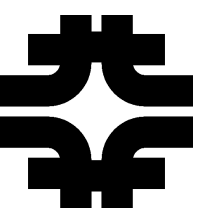# Latest Results from The Higgs Search at DØ
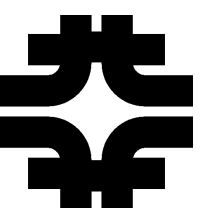
Satish Desai – Fermilab
Joint Experimental-Theoretical Seminar
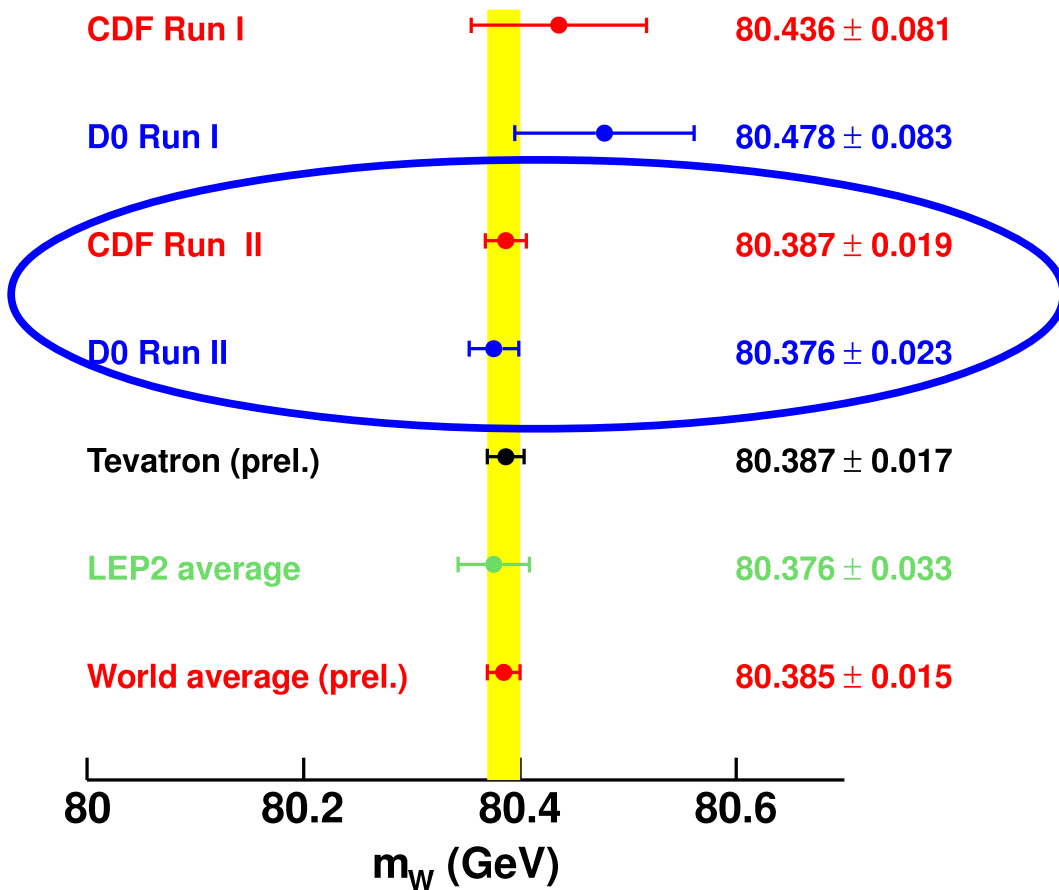### 7 March 2012

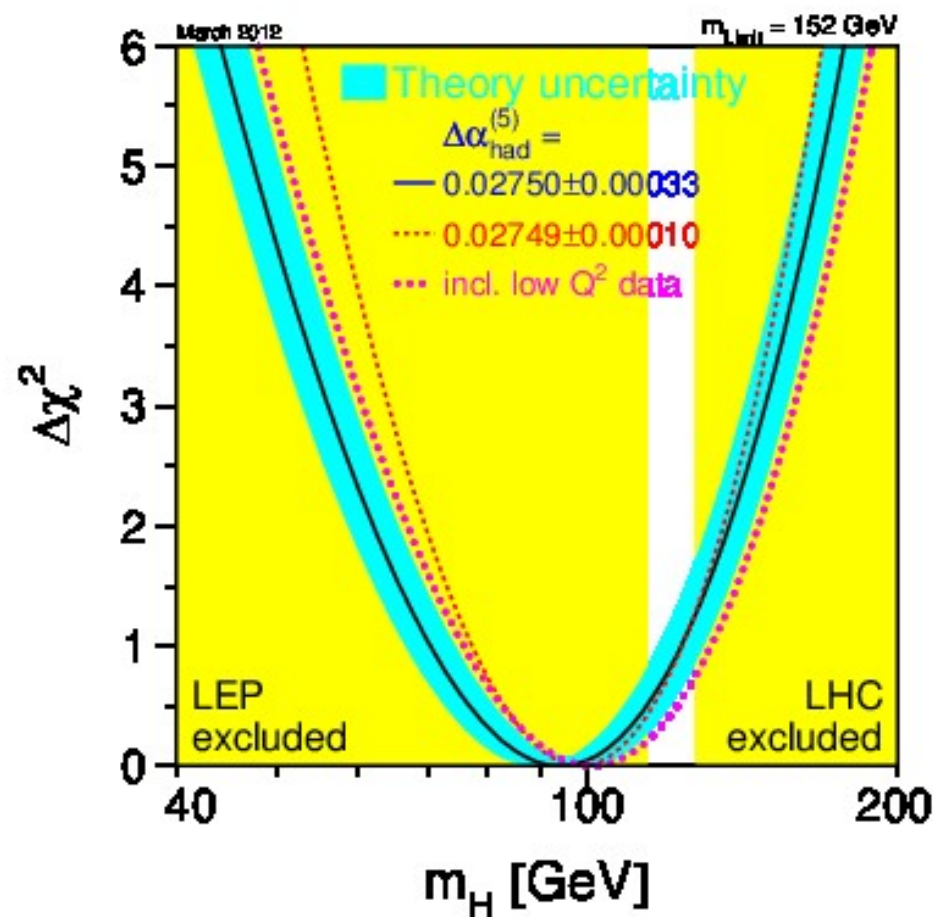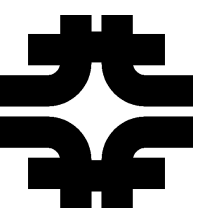## On Behalf of the DØ Collaboration

What Do We Know So Far?

Fits and Constraints

CDF Run I 80.436 ± 0.081

D0 Run I 80.478 ± 0.083

CDF Run II 80.387 ± 0.019

D0 Run II 80.376 ± 0.023

Tevatron (prel.) 80.387 ± 0.017

LEP2 average 80.376 ± 0.033

World average (prel.) 80.385 ± 0.015
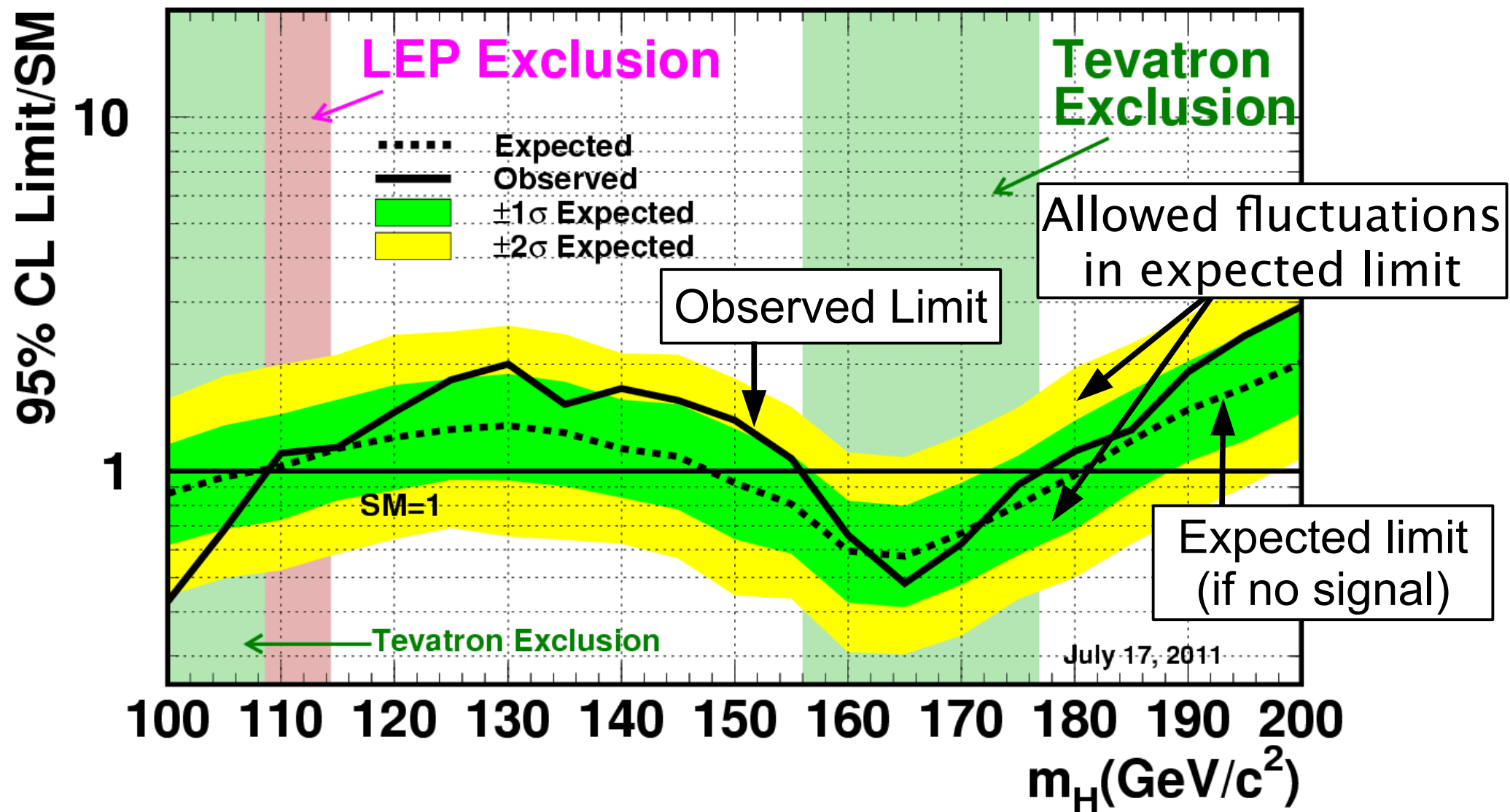
m_W (GeV)

From indirect constraints:
$M_H < 152$ GeV

Direct Searches

Summer 2011 Results

Tevatron Run II Preliminary, L ≤ 8.6 fb^{-1}

Summer 2011 Results

Tevatron Run II Preliminary, $L \leq 8.6$ fb^{-1}

Exclude: 100 – 108 GeV/c^2, 156 – 177 GeV/c^2
Limits at M_H = 115 GeV/c^2:
Exp: 1.16×σ_{SM} Obs: 1.17×σ_{SM}

Direct Searches

ATLAS Preliminary — 2011 Data

Observed / Expected, $\pm 1\sigma$, $\pm 2\sigma$

$\int L\,dt = 1.0\text{-}4.9\ \text{fb}^{-1}$

$\sqrt{s} = 7\ \text{TeV}$

95% CL Limit on σ/σ_{SM}
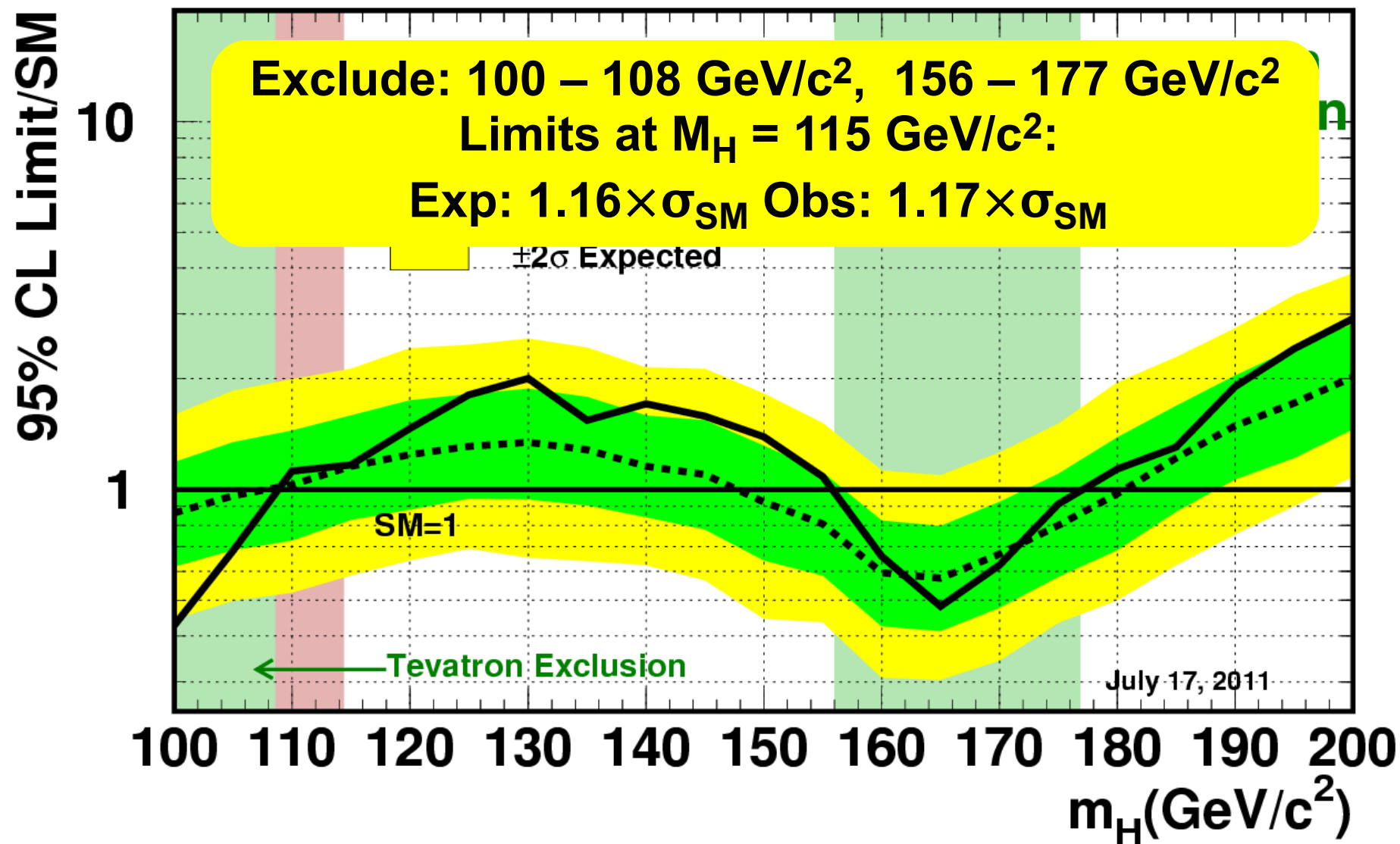
CLs Limits
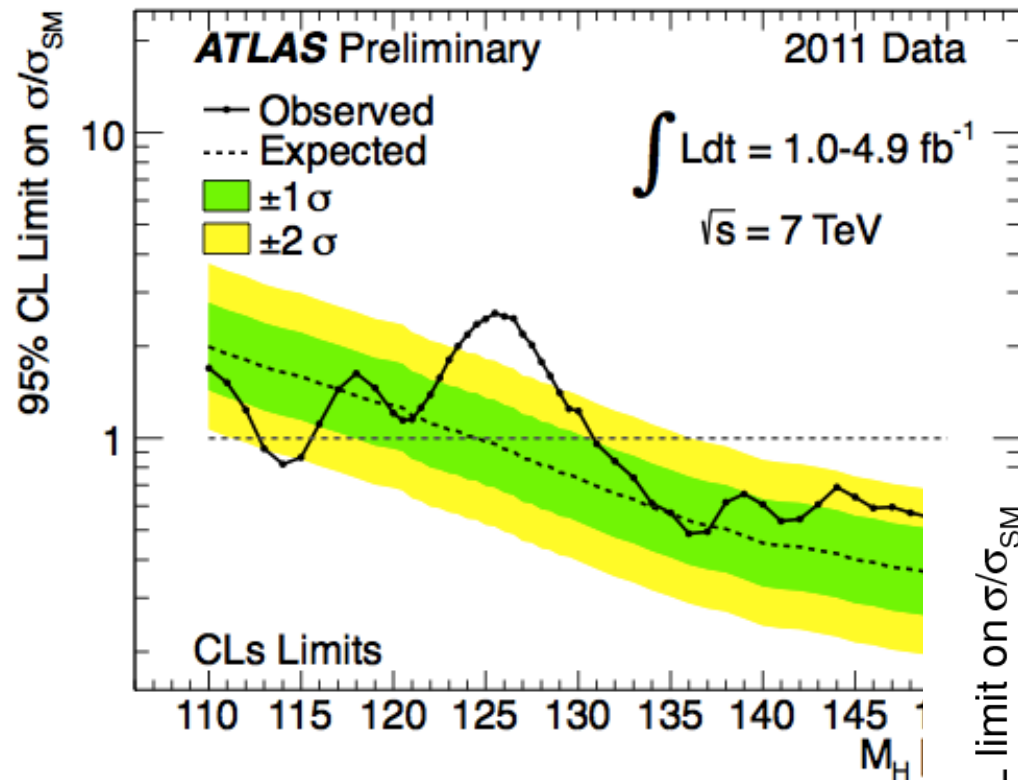
December 2011

Allowed at 95% CL:
~~115~~ $< M_H <$ 127 GeV
122.5

CMS Preliminary, $\sqrt{s} = 7\ \text{TeV}$
Combined, $L_{int} = 4.6\text{-}4.7\ \text{fb}^{-1}$

Observed / Expected $\pm 1\sigma$ / Expected $\pm 2\sigma$ / LEP excluded / Tevatron excluded / CMS excluded
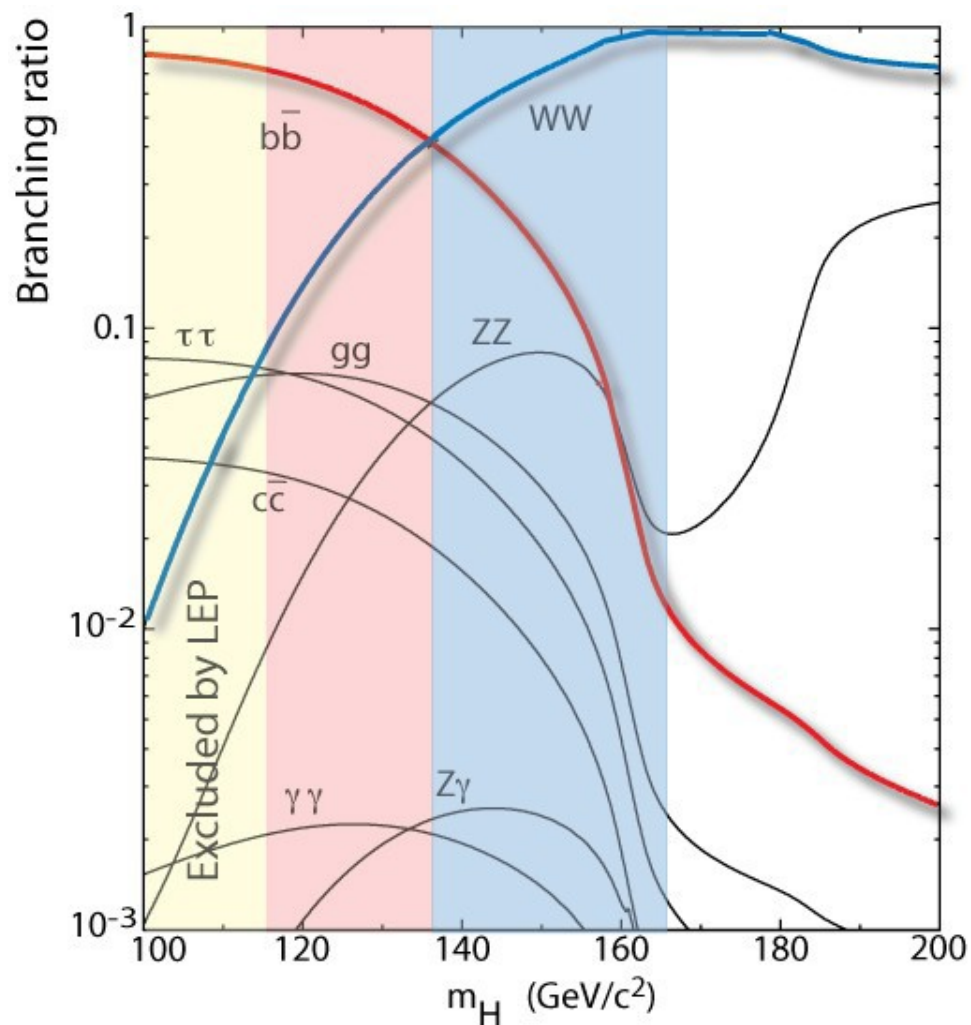
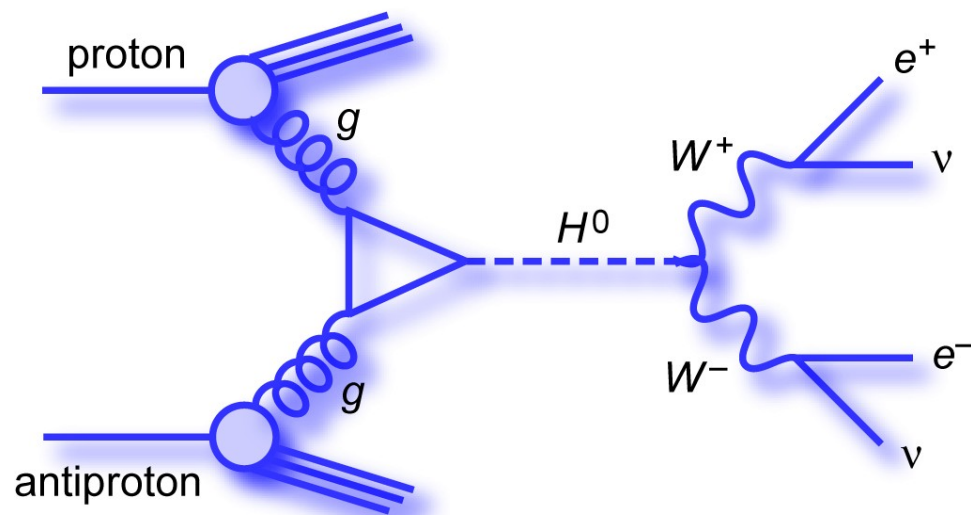95% CL limit on σ/σ_{SM}

Higgs boson mass (GeV/c^2)
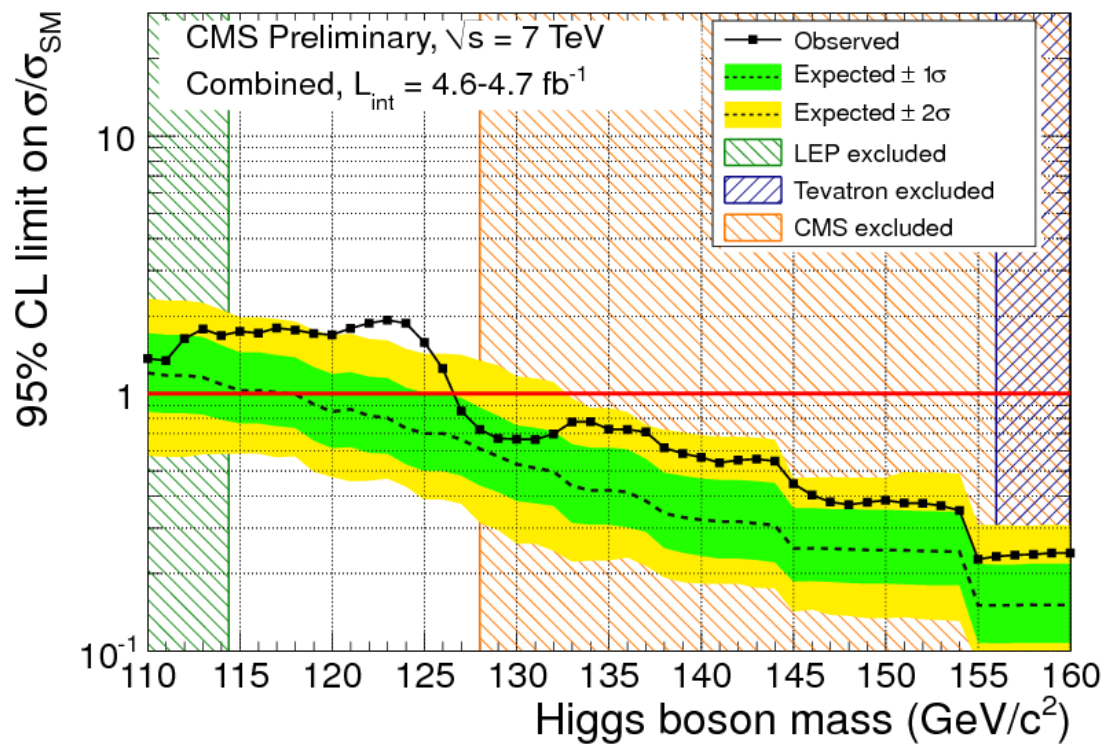
What to Look For

Experimental Signatures

For the important region:
Main Decay: H → b̄b
H → WW still important
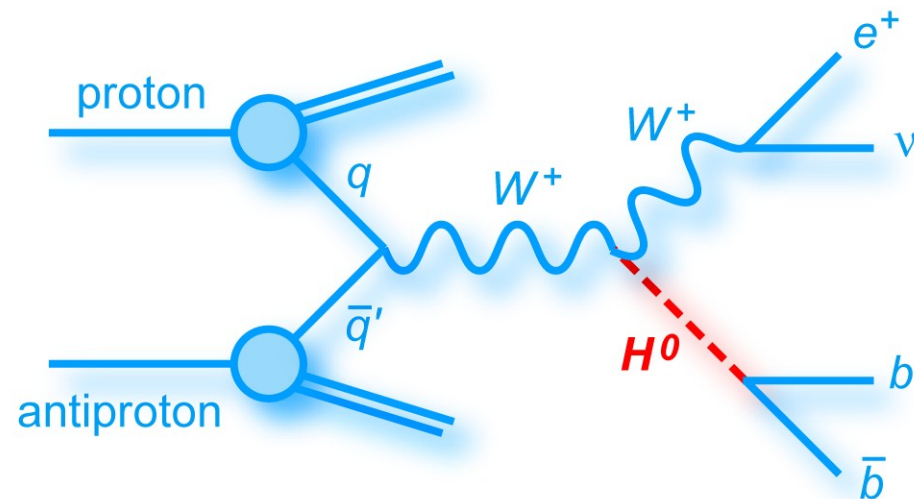
Signals and Backgrounds

$H \rightarrow WW \rightarrow l\nu l\nu$: S/B $O(1/100)$

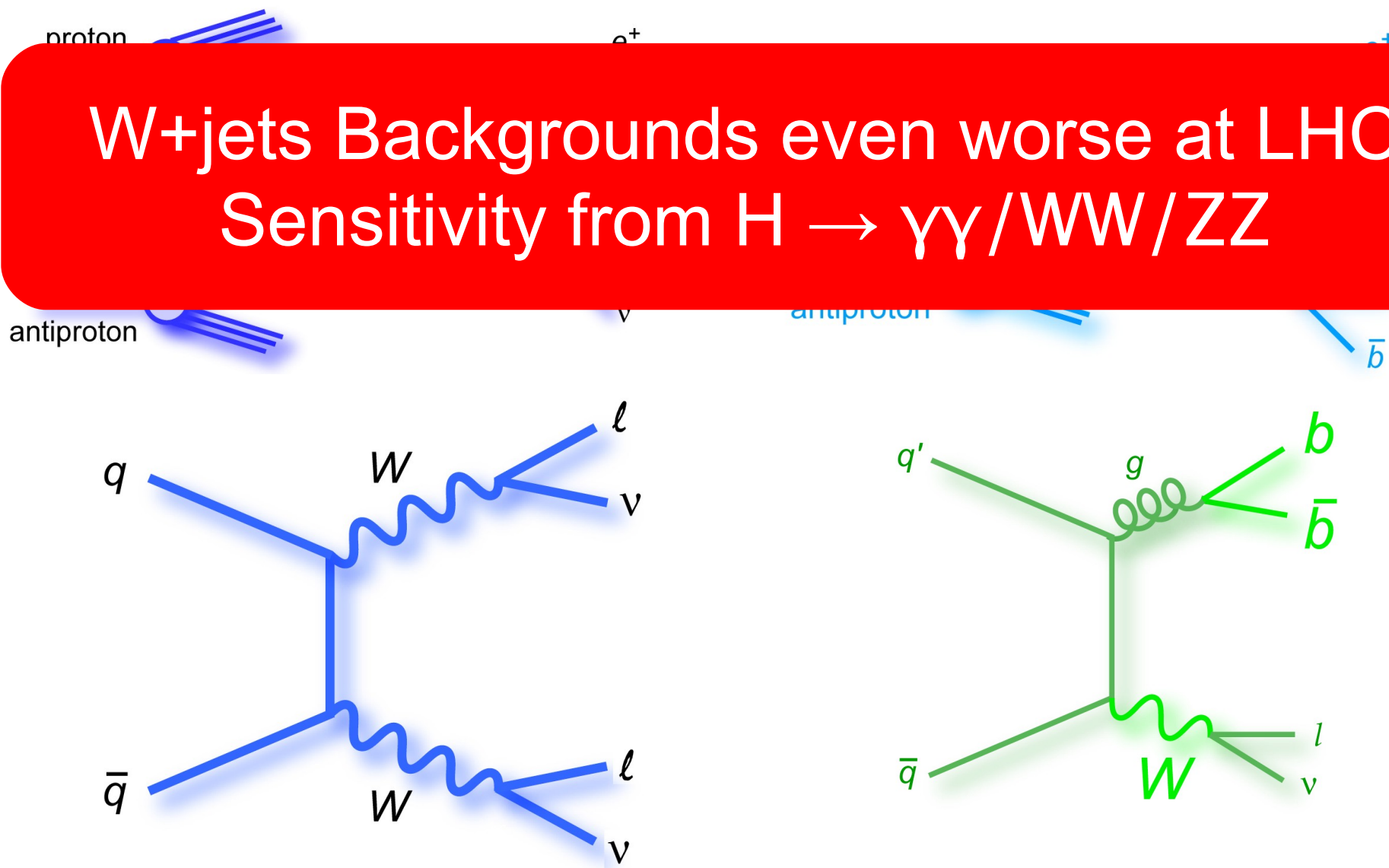$WH \rightarrow l\nu b\overline{b}$: S/B $O(1/1000)$

$H \to WW \to l\nu l\nu$: S/B $O(1/100)$

$WH \to l\nu b\bar{b}$: S/B $O(1/1000)$

W+jets Backgrounds even worse at LHC:
Sensitivity from H → γγ/WW/ZZ

$H \to WW \to l\nu l\nu$: S/B O(1/100) $WH \to l\nu b\bar{b}$: S/B O(1/1000)

proton

antiproton

q

$\bar{q}$

W

ℓ

ν

e^+

b

$\bar{b}$

$\bar{q}$

W

l

ν

W+jets Backgrounds even worse at LHC: Sensitivity from H → γγ/WW/ZZ

Tevatron still the place to study H → b$\bar{\text{b}}$
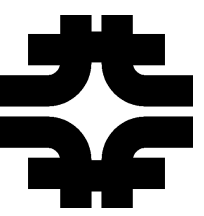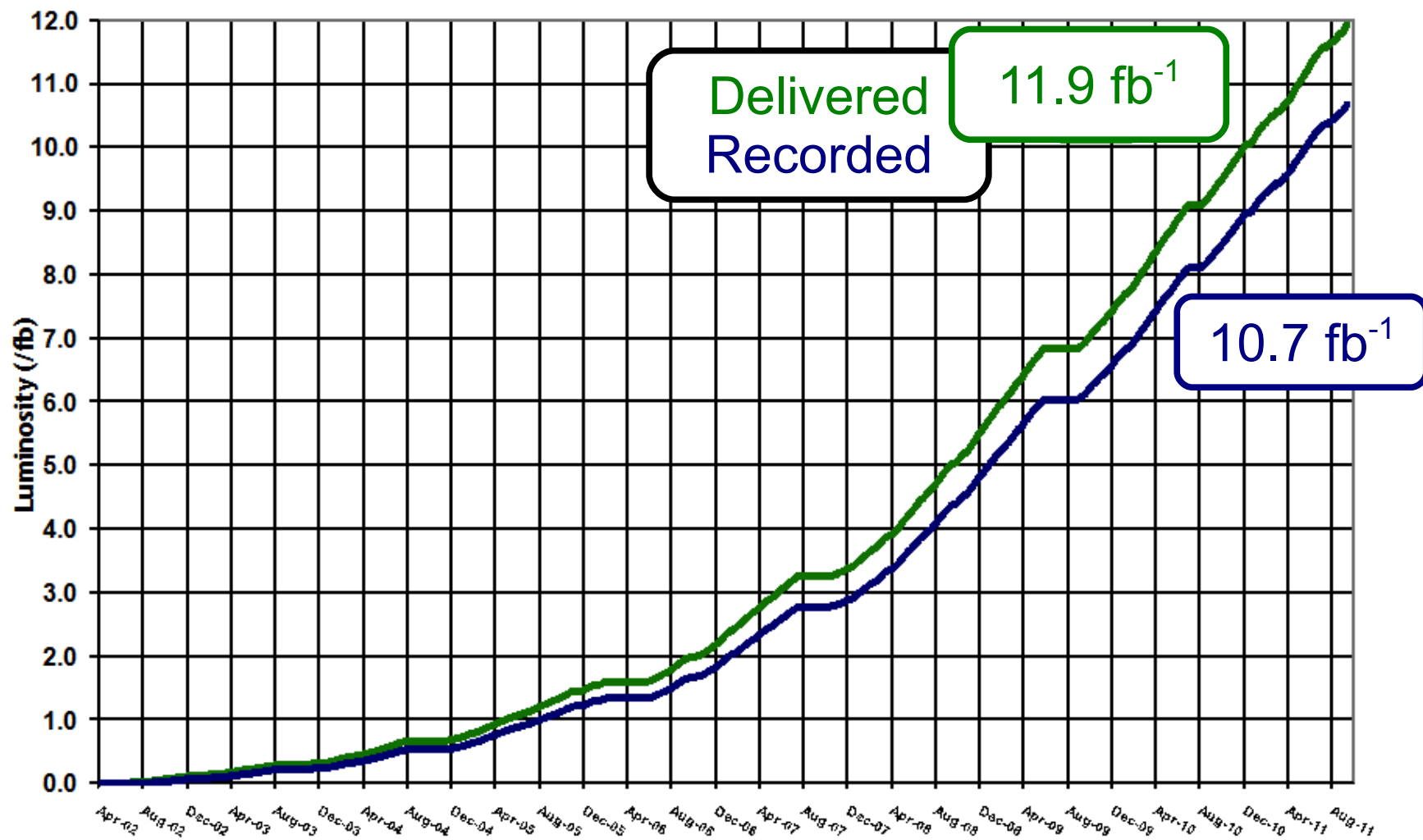
Searches at DØ

Detector Performance

Detector Performance

Run II Integrated Luminosity

19 April 2002 - 30 September 2011

Delivered — 11.9 fb^{-1}
Recorded — 10.7 fb^{-1}
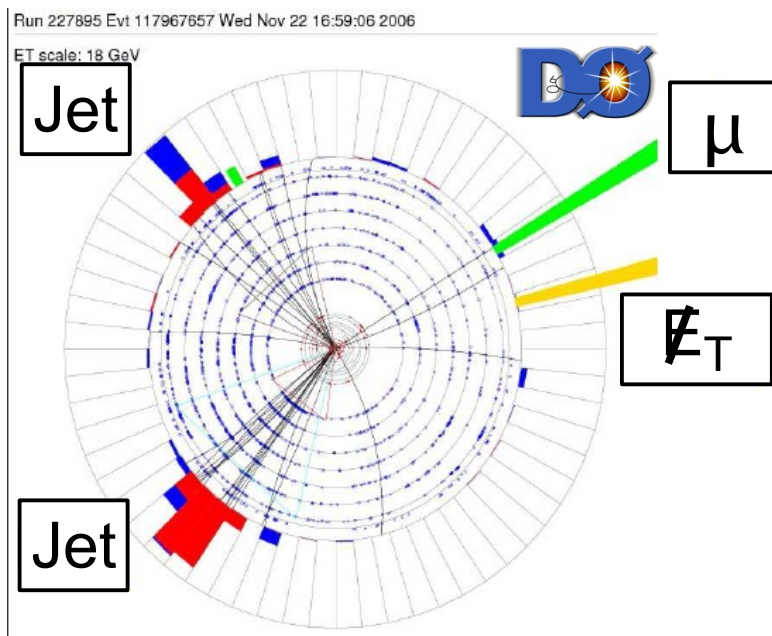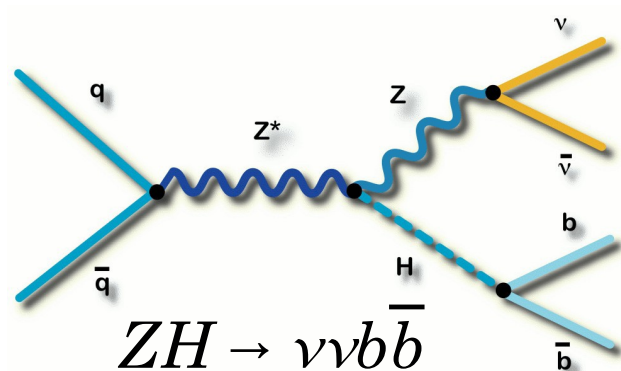
Thanks to Accelerator Division!!

None of this would be possible without you!

Searching for H → b$\bar{\text{b}}$

$$ZH \to llb\bar{b}$$

$$WH \to l\nu b\bar{b}$$

$$ZH \to \nu\nu b\bar{b}$$

Run 227895 Evt 117967657 Wed Nov 22 16:59:06 2006
ET scale: 18 GeV

Jet

Jet

μ

$\not{E}_T$

V(→lν)+2 jets, Pre Tag

$\times 10^3$

DØ Preliminary, L=9.7 fb^{-1}

Events

- Data
- Multijet
- V+lf
- V+hf
- t$\bar{t}$
- single-top
- VV
- Signal (x1000)

$$WH \to l\nu b\bar{b}$$

W Transverse Mass (GeV/c^2)
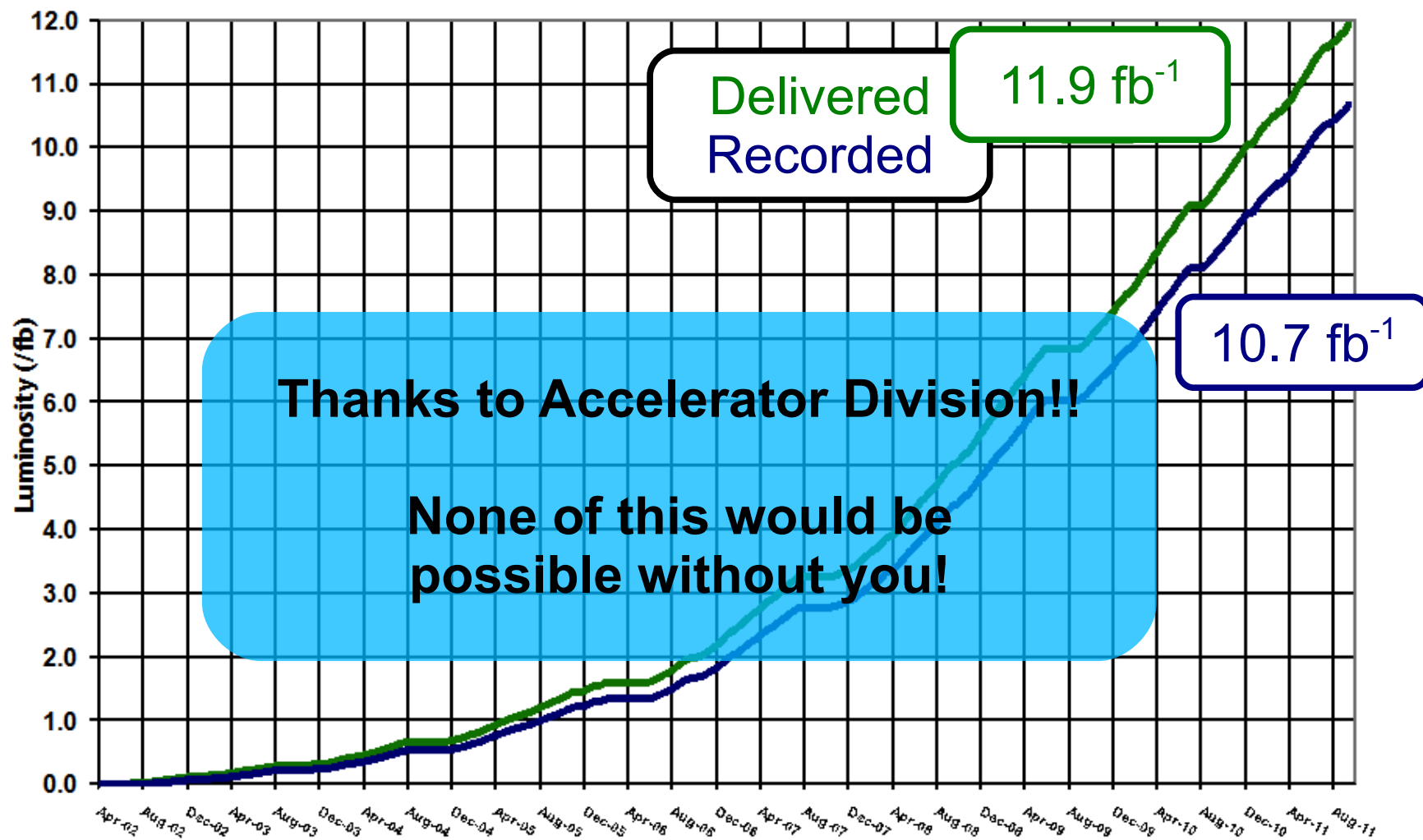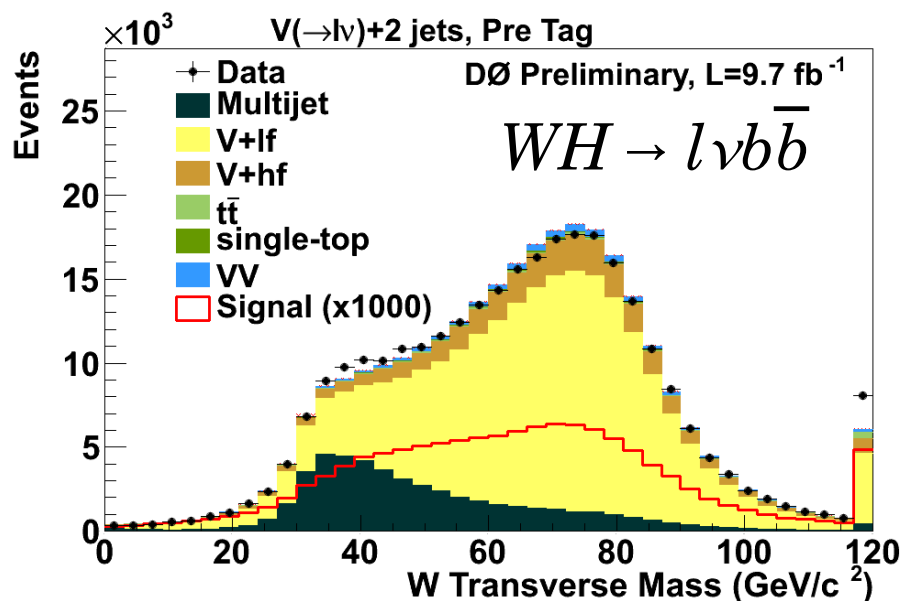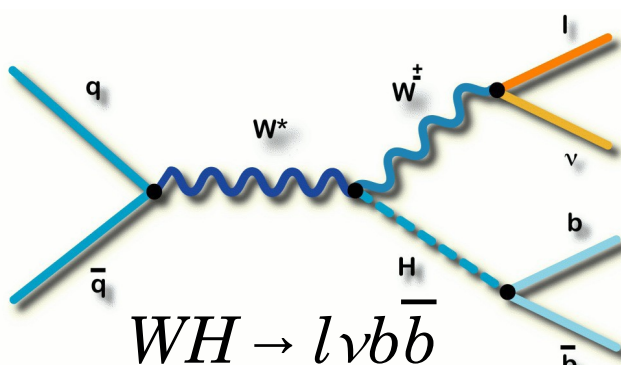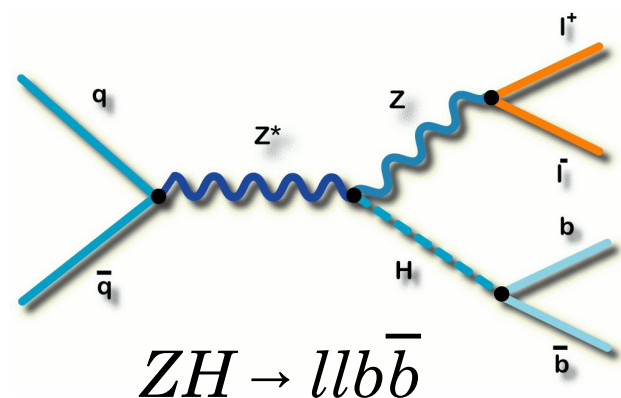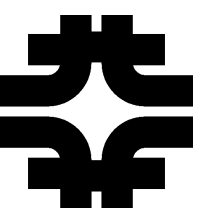
Background Modeling

Must rely on Monte Carlo event generators to model W/Z+jets

Need detailed studies to understand what they are doing
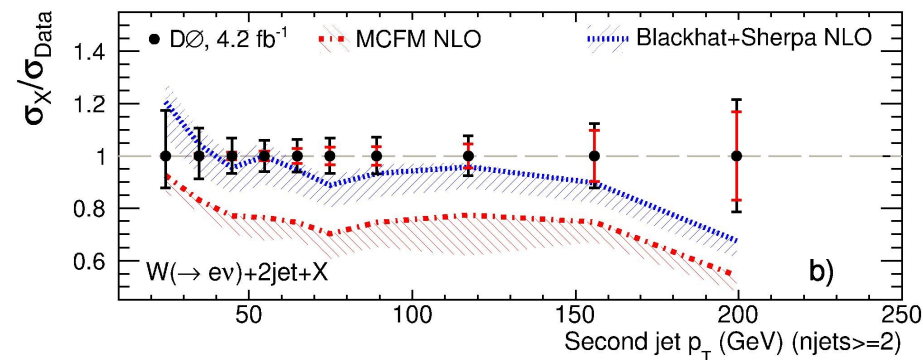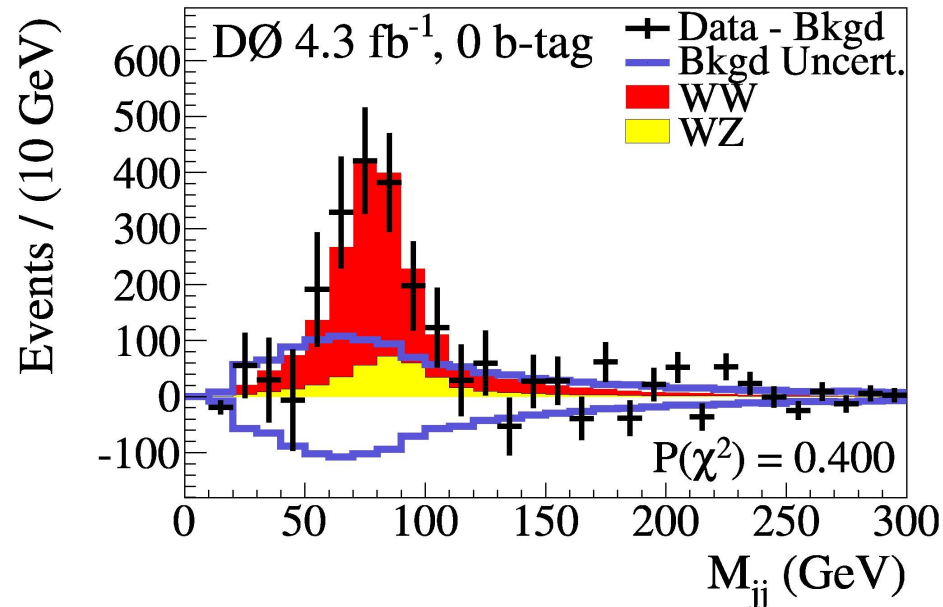
Avoid washing out a signal or creating false positives

Cross check against dedicated measurements
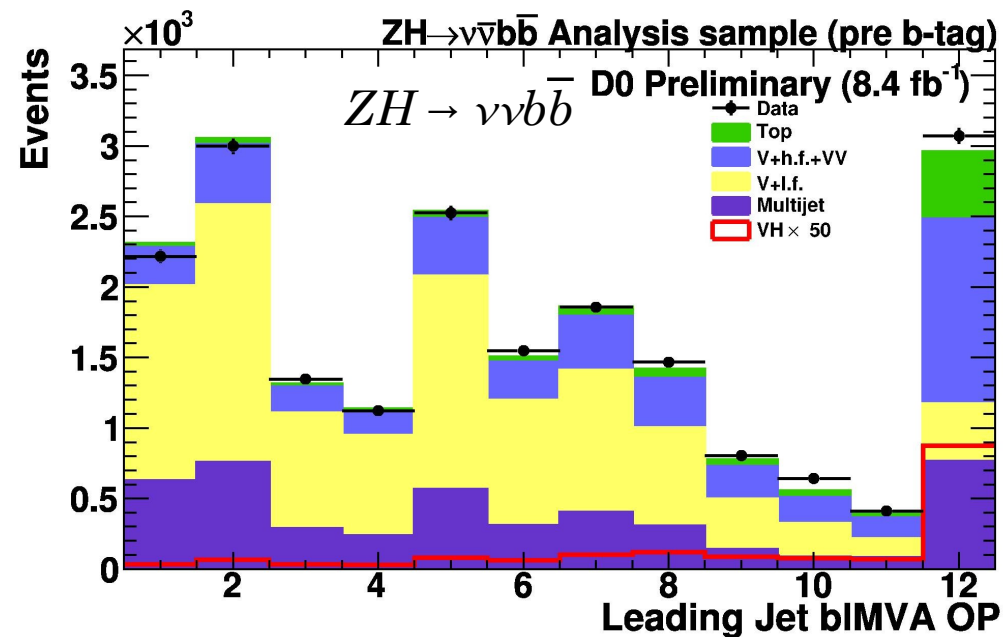
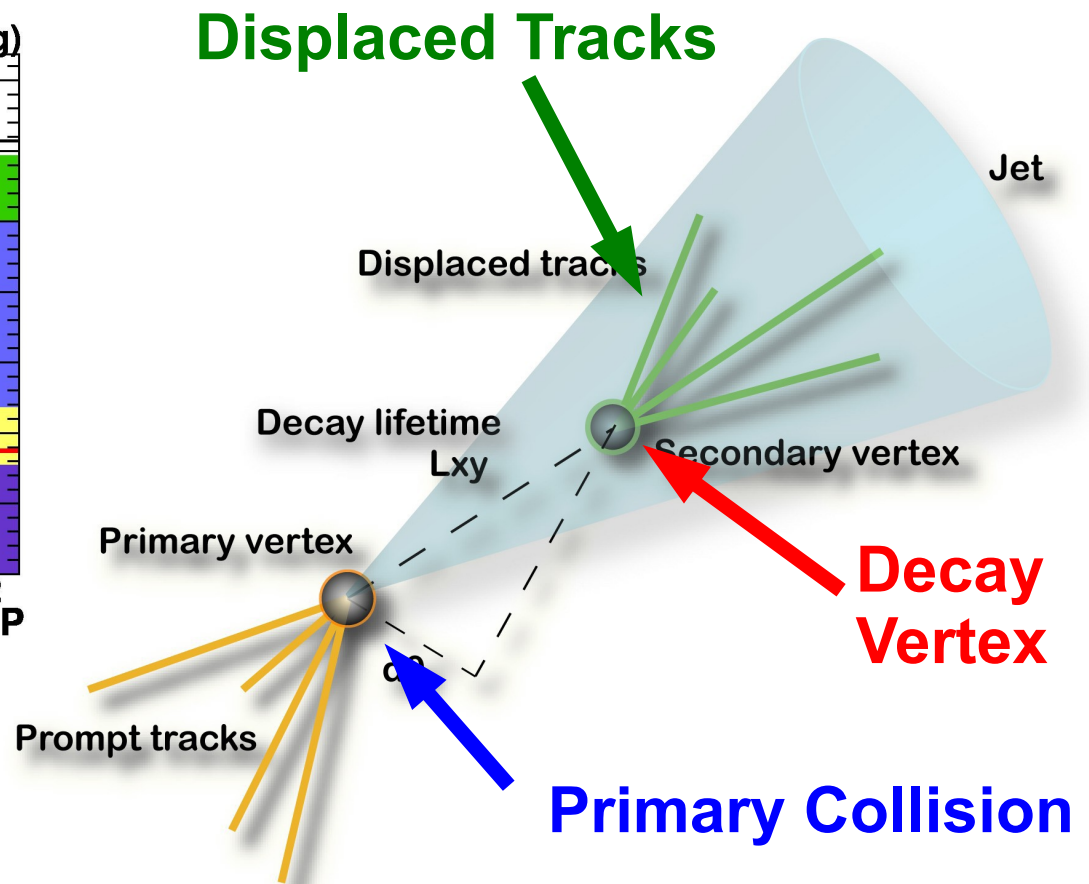**Try to extract known signals**

W+jets – PLB 705, 200 (2011)
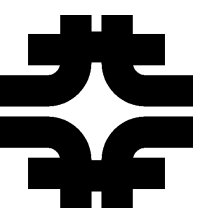

WW/WZ → lv+jets
Submitted to PRL (Dec, 2011)

b-tagging

ZH→ννbb̄ Analysis sample (pre b-tag)

$ZH \rightarrow \nu\nu b\bar{b}$

D0 Preliminary (8.4 fb⁻¹)

- Data
- Top
- V+h.f.+VV
- V+l.f.
- Multijet
- VH × 50

Leading Jet bIMVA OP

	Efficiency
b-jets	50%-70%
light jets	0.5%-4.5%

Displaced Tracks

Jet

Displaced tracks

Decay lifetime Lxy

Secondary vertex

Decay Vertex

Primary vertex

Prompt tracks

Primary Collision

Combine information with a multivariate b-tagger

Validation With Dibosons

Search for:
$$WZ/ZZ \rightarrow X + b\bar{b}$$

Identical Final State to
$$WH/ZH \rightarrow X + b\bar{b} \text{ searches}$$
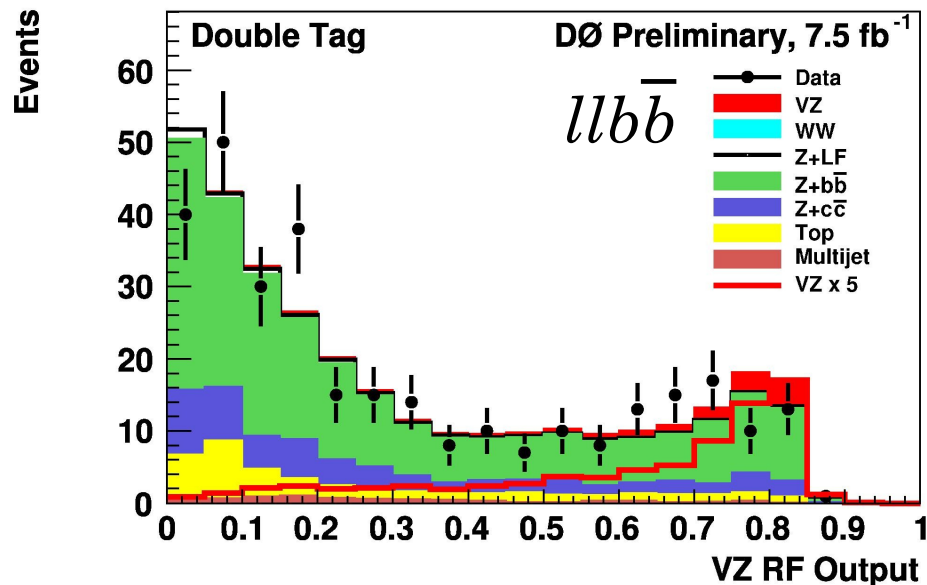**Cross section is ~5 times higher**

Use same search strategy:
Same event selection
Same MVA techniques
Same statistical analysis tools
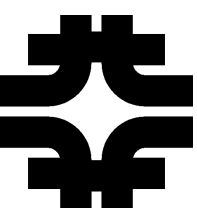
Seeing this signal is a
critical test of analysis strategy

For details: W&C by K Herner from 9 December 2011

CDF results and Combination in the following talk

Validation With Dibosons

Search for:
WZ/ZZ → X + b$\bar{\text{b}}$

Identical Final State to
WH/ZH → X + b$\bar{\text{b}}$ searches
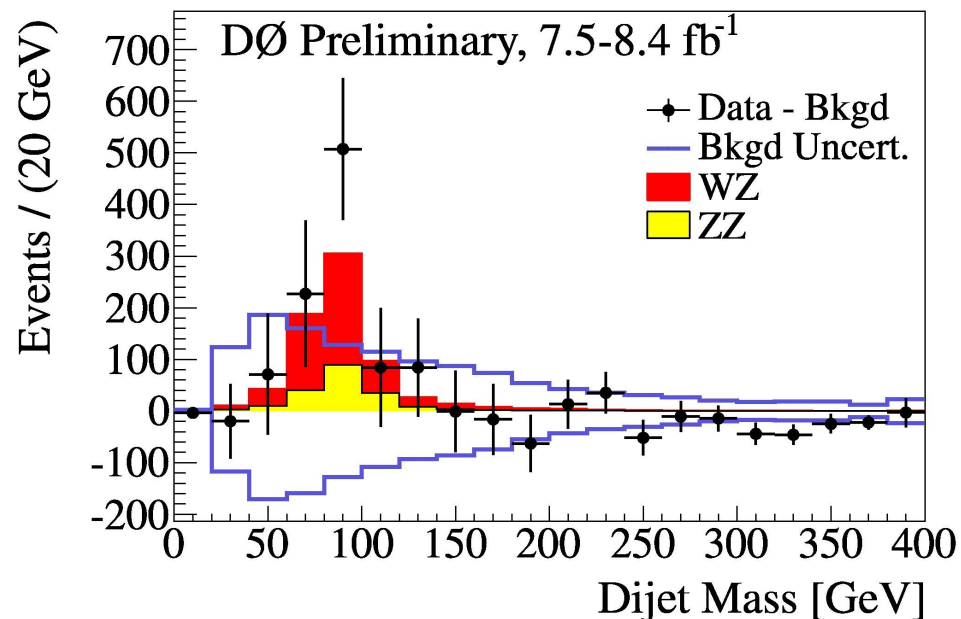**Cross section is ~5 times higher**

Use same search strategy:
Same event selection
Same MVA techniques
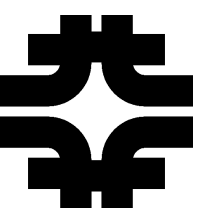**Same statistical analysis tools**

Seeing this signal is a
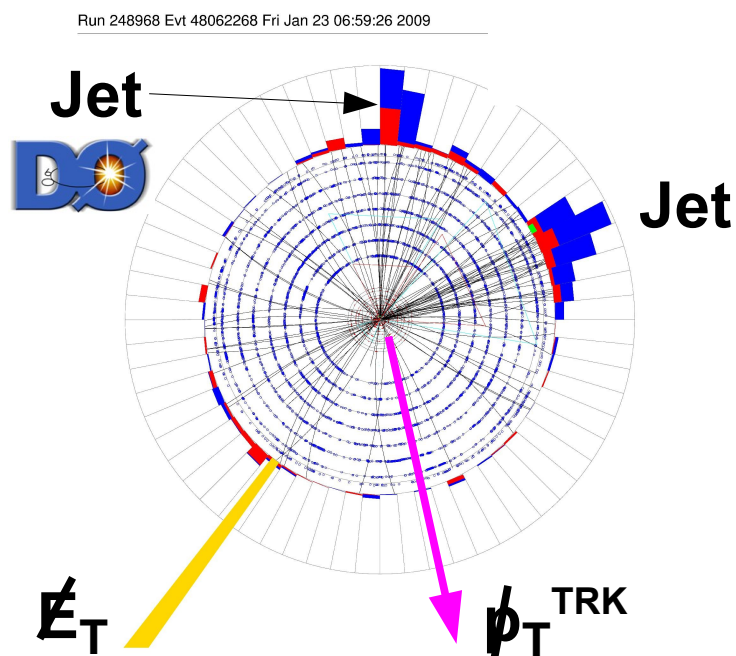**critical test of analysis strategy**

Significance: 3.3σ

Cross Section:
Measure: 5.0±1.0±1.3 pb
Theory: 4.4±0.3 pb

DØ Preliminary, 7.5-8.4 fb^{-1}

Legend:
- Data - Bkgd
- Bkgd Uncert.
- WZ
- ZZ

y-axis: Events / (20 GeV)
x-axis: Dijet Mass [GeV]

Improvements for $\not{E}_T + b\bar{b}$

50% of signal is from WH with lost leptons

Event level b-tagging

Run 248968 Evt 48062268 Fri Jan 23 06:59:26 2009

Jet

Jet

$\not{E}_T$

$\not{p}_T^{TRK}$

Use $\not{p}_T^{TRK}$ to suppress multijet background

ZH→ν$\bar{\nu}$b$\bar{b}$ Analysis sample (Pre b-tag)

MJDT > -0.3

D0 Preliminary (9.5 fb^{-1})

Events

10^4

10^3

10^2

5   10   15   20   25 L_{bb}

Data
Top
V+h.f.+VV
V+l.f.
Multijet
VH(115) × 50

Add together b-taggger outputs for both jets

Cut on the sum instead of per jet cuts

Exclude isolated tracks from $\not{p}_T^{TRK}$ to improve WH acceptance by 10%

50% of signal is from WH with lost leptons

Event level b-tagging

Run 248968 Evt 48062268 Fri Jan 23 06:59:26 2009

Jet

Jet

$\not{E}_T$

$\not{p}_T^{TRK}$

Use $\not{p}_T^{TRK}$ to suppress multijet background

Exclude isolated tracks from $\not{p}_T^{TRK}$ to improve WH acceptance by 10%

$ZH \rightarrow \nu\bar{\nu}b\bar{b}$ Analysis sample (Pre b-tag)

MJDT > -0.3

D0 Preliminary (9.5 fb⁻¹)

Events

10^4

10^3

- Data
- Top
- V+h.f.+VV
- V+l.f.
- Multijet
- VH(115) × 50

5 10 15 20 25

L_{bb}

25% improvement in sensitivity expected from additional data: 6%
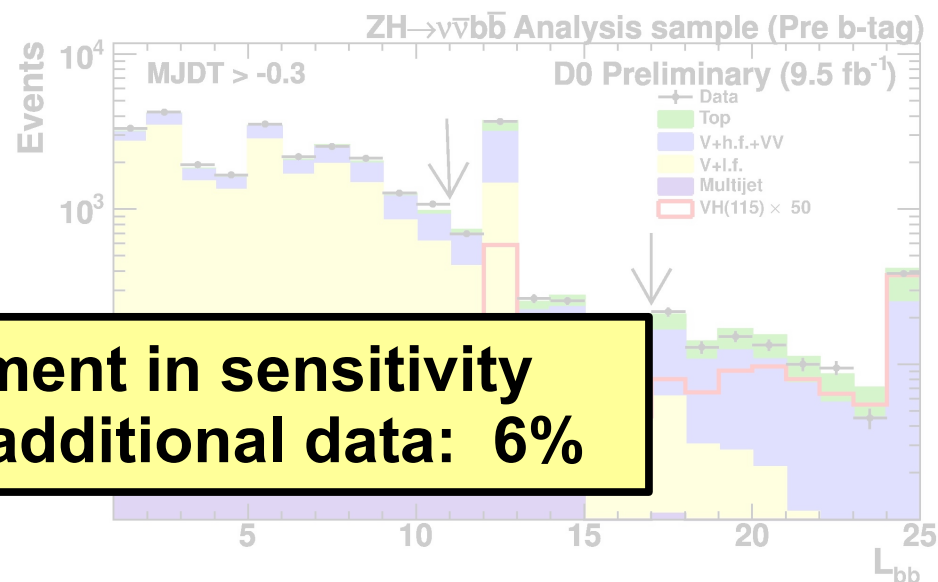
Add together b-taggger outputs for both jets

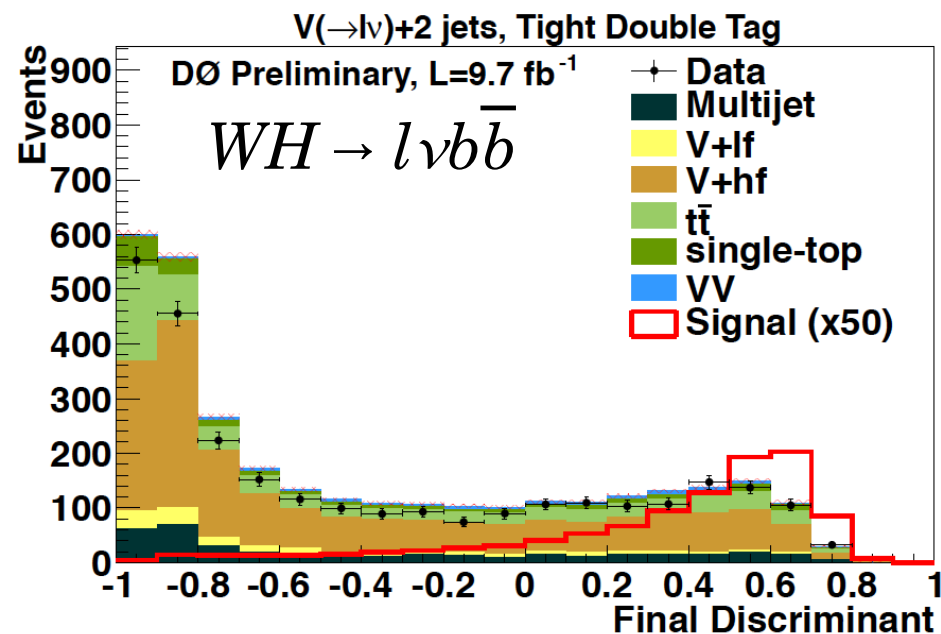**Cut on the sum instead of per jet cuts**

Multivariate Methods

S/B in most sensitive channels: O(1/100)

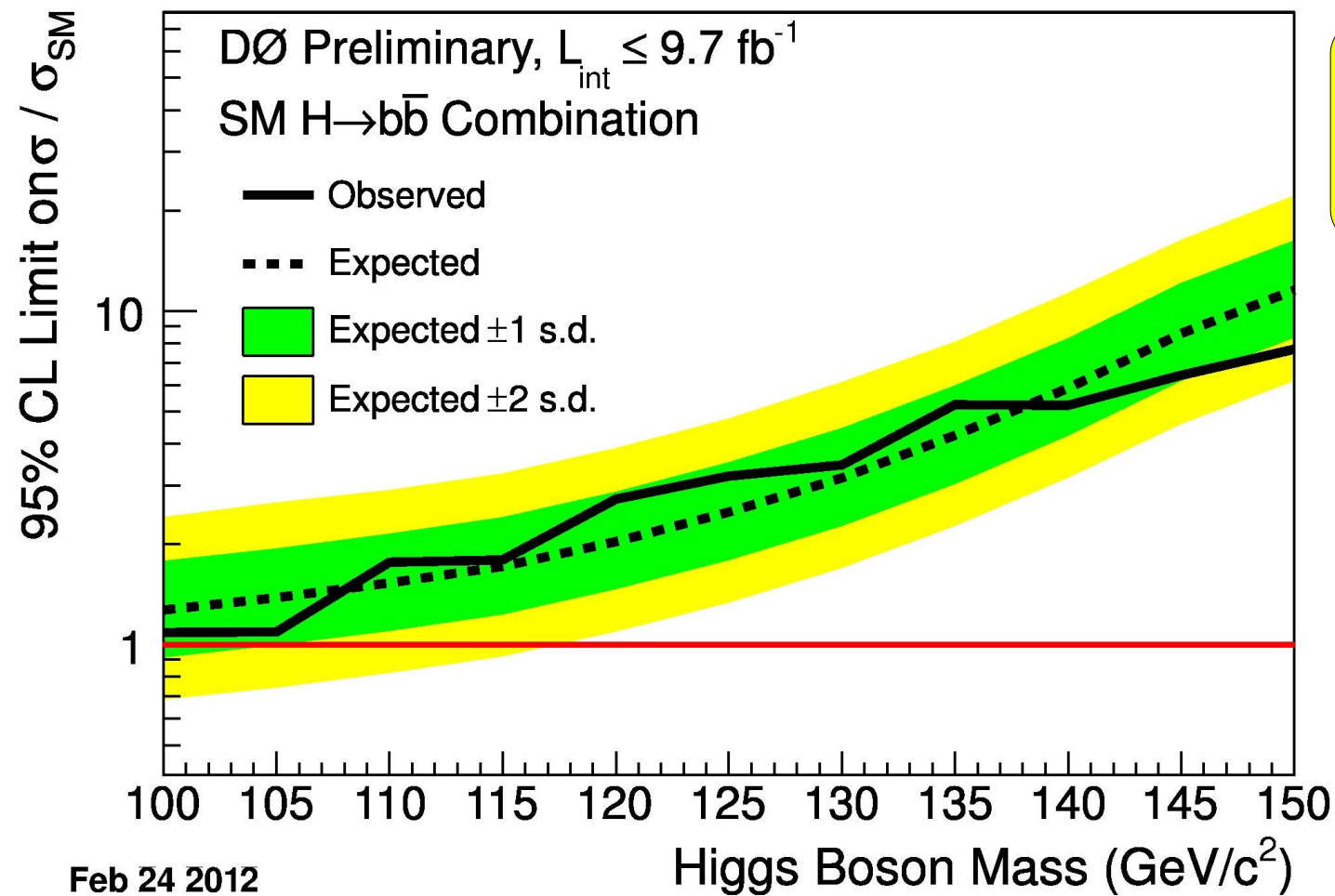**Signal extraction relies on multivariate techniques**

Neural networks, matrix elements, boosted decision trees...

Use all of the information in the event to decide how signal-like it is

V($\to l\nu$)+2 jets, Tight Double Tag

D∅ Preliminary, L=9.7 fb^{-1}

$$WH \to l\nu b\bar{b}$$

Data
Multijet
V+lf
V+hf
$t\bar{t}$
single-top
VV
Signal (x50)

Final Discriminant

Double Tag   D∅ Preliminary, 9.7 fb^{-1}

$$ZH \to llb\bar{b}$$

Data
Z+LF
Z+b$\bar{b}$
Z+c$\bar{c}$
Top
Diboson
Multijet
ZH x 20

RF Output

Limits for H → bb̄

DØ Preliminary, $L_{int} \leq 9.7$ fb^{-1}

SM H→bb̄ Combination

— Observed
···· Expected
▇ Expected ±1 s.d.
▇ Expected ±2 s.d.

95% CL Limit on σ / σ_{SM}

Higgs Boson Mass (GeV/c^2)

Feb 24 2012
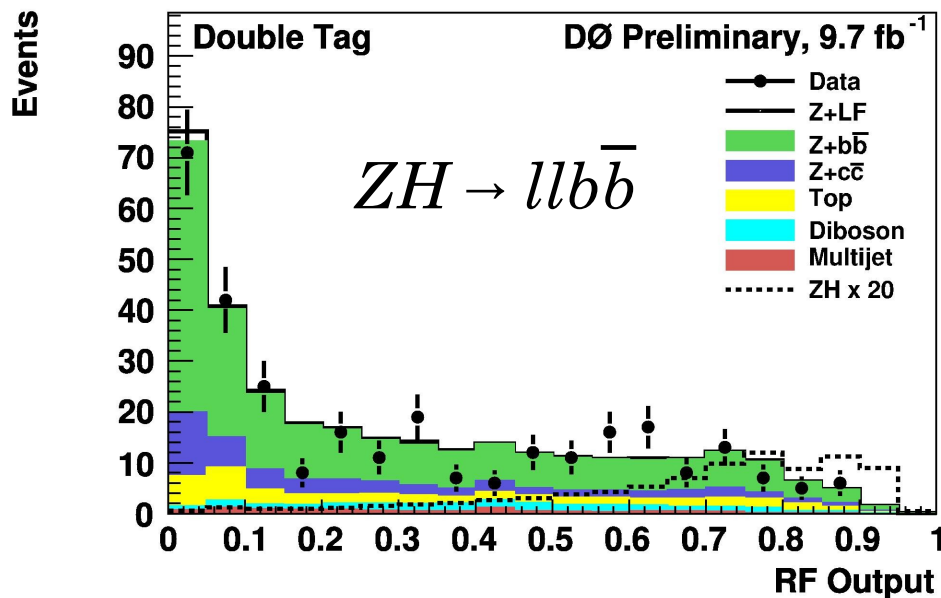
Limits at M_H = 115 GeV:
Exp: 1.71 × σ_{SM}
Obs: 1.79 × σ_{SM}

Limits at M_H = 125 GeV:
Exp: 2.49 × σ_{SM}
Obs: 3.20 × σ_{SM}

Searching for H → WW
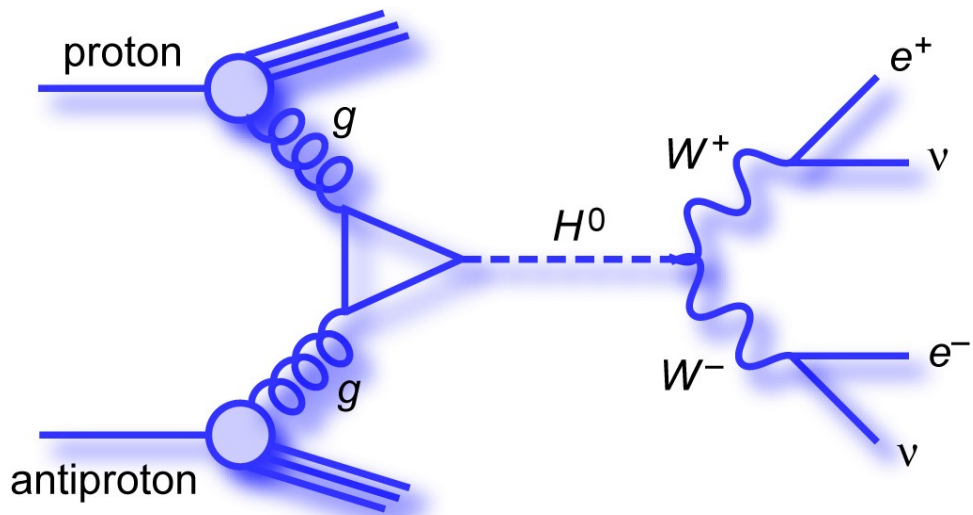
Final states: ee, μμ and eμ

Exploit spin correlations to control backgrounds

Z → ll is major background for ee and μμ channels
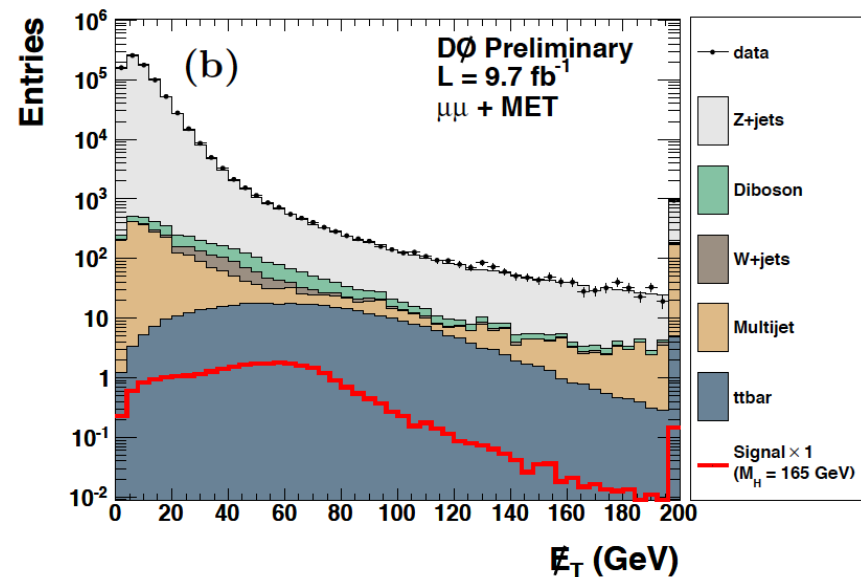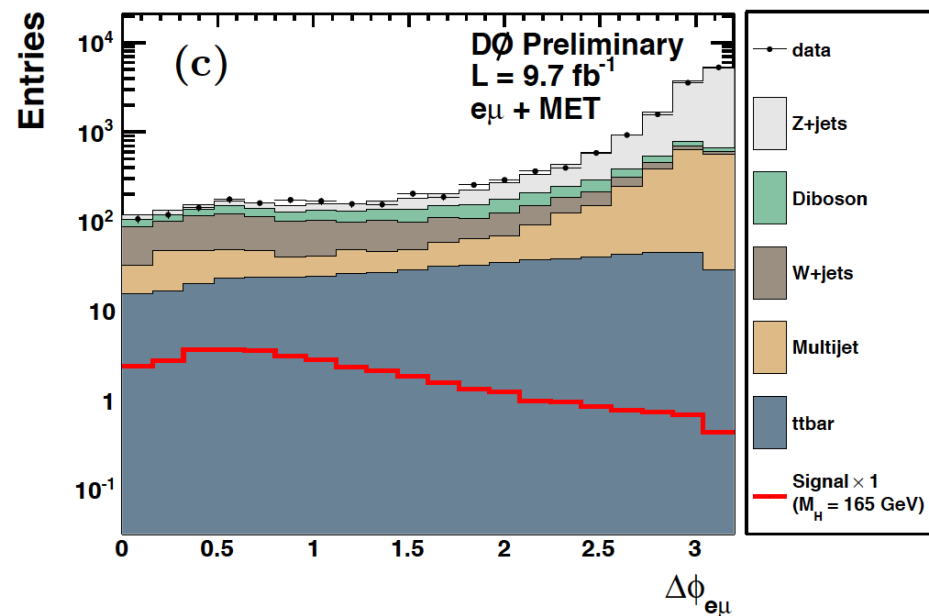
Searching for H → WW

Use Boosted Decision Trees to control backgrounds from Z → ee, μμ

Signal and background composition vary with jet multiplicity

Consider multiple signals:
Gluon fusion
Vector boson fusion
H → ZZ...

Z → ee Rejection BDT
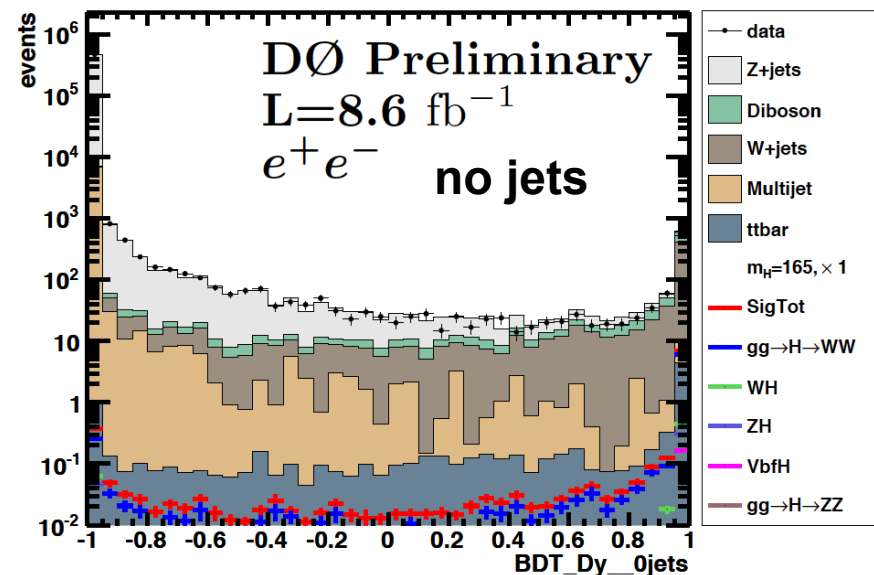
Final Discriminant (two jets)
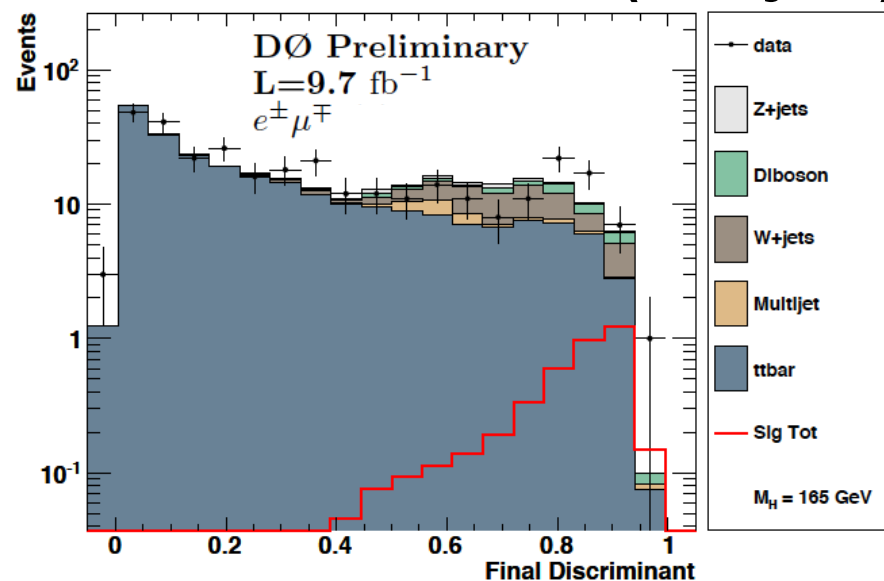
H → WW Results
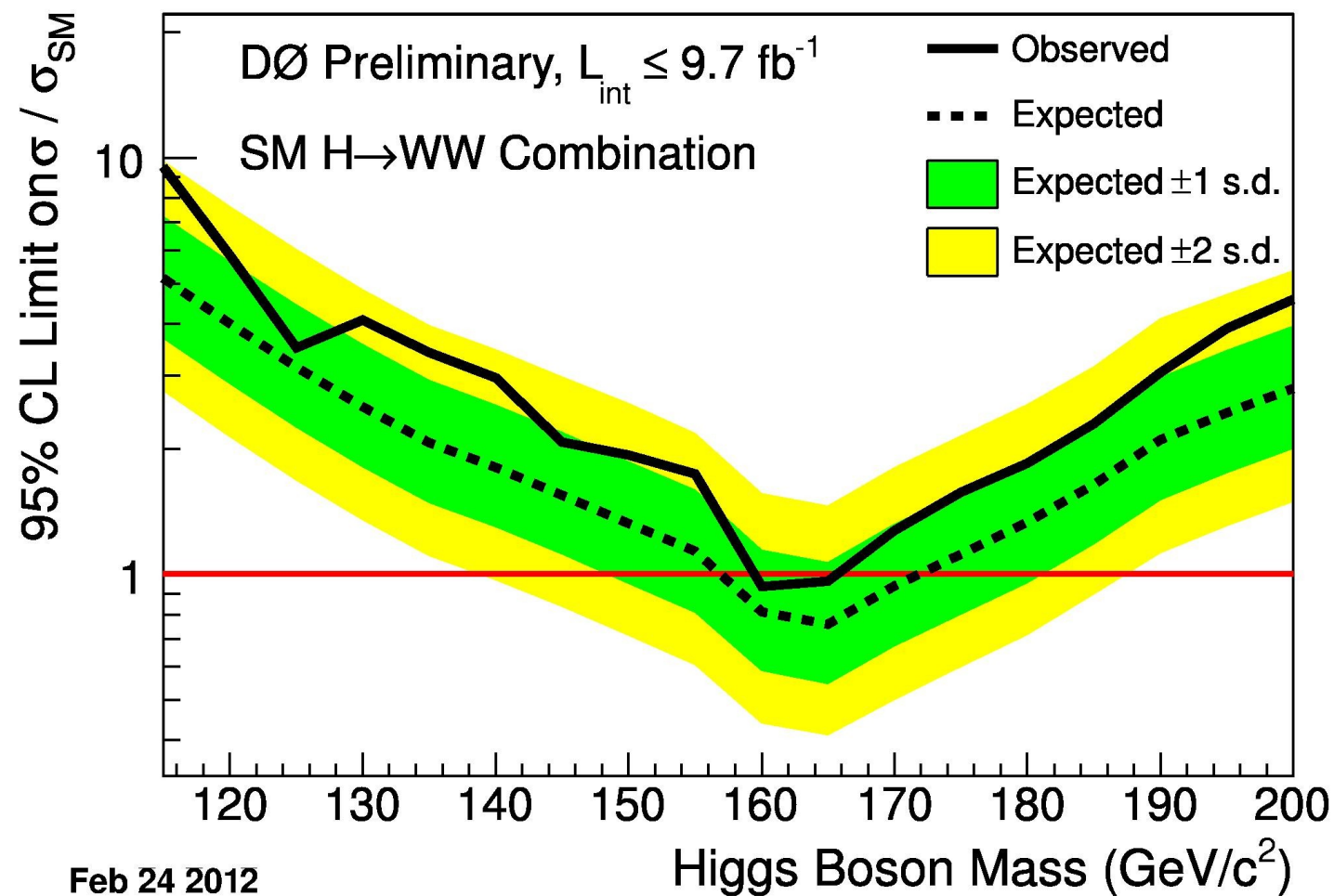
Limits at M_H = 125 GeV:
Exp: 3.14 × σ_{SM}
Obs: 3.50 × σ_{SM}

Competitive with individual H→b$\bar{\text{b}}$ searches

Extending the Search

Same Sign eµ
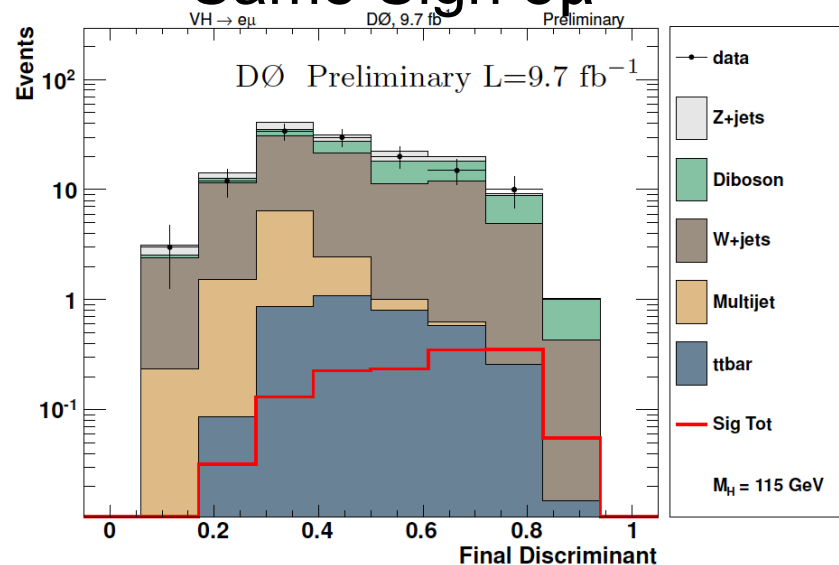
Search for W/ZH → VVV

Look for final states with
same sign dileptons, trileptons

Low rates, but low backgrounds

Searches with Taus

D0 L=7.3 fb⁻¹ (a)
- data
- Z+jets
- W+jets
- other
- multijets
- signal(x 100)

$\mu\tau_H$ +0/1 jet

Events/0.05 vs Final Discriminant
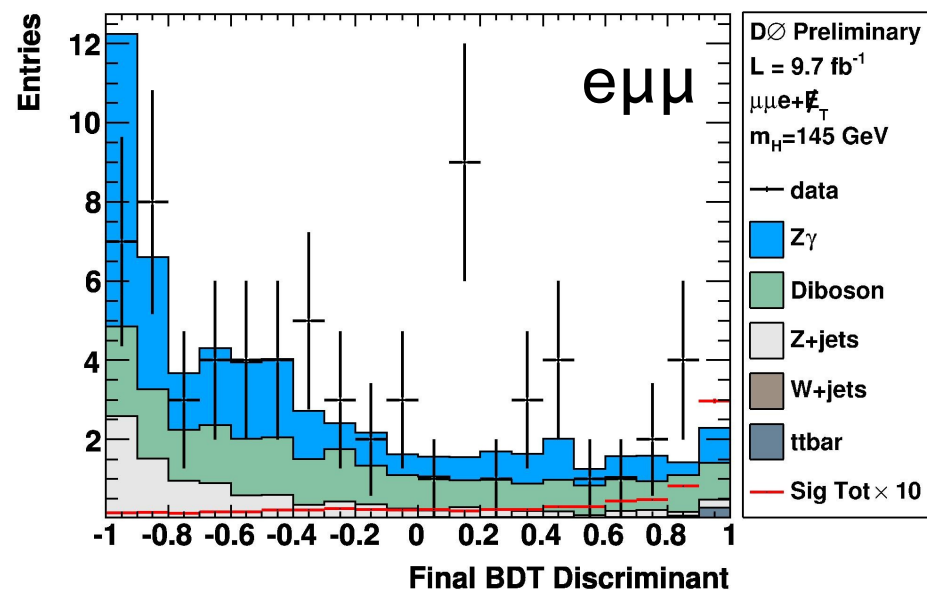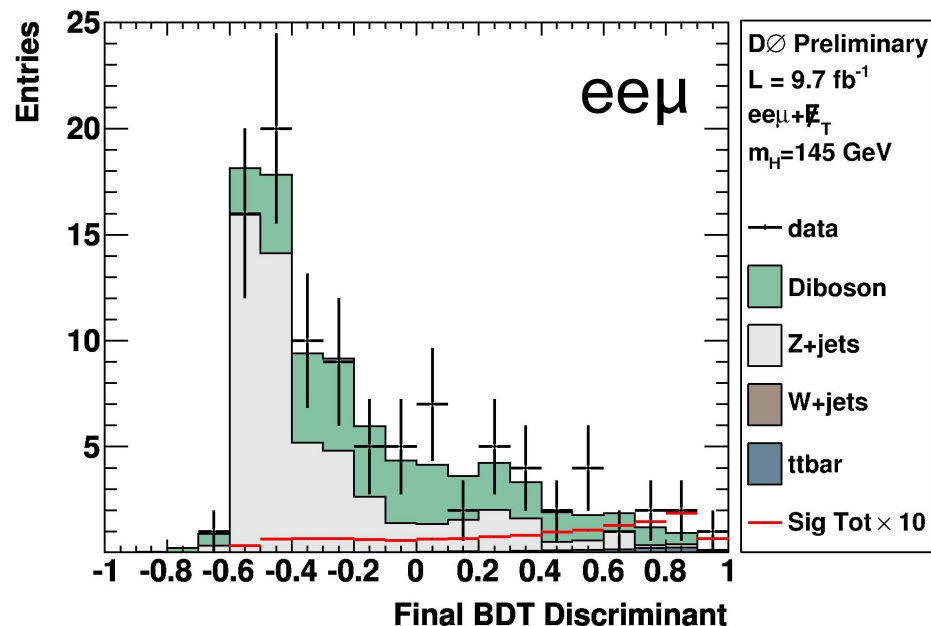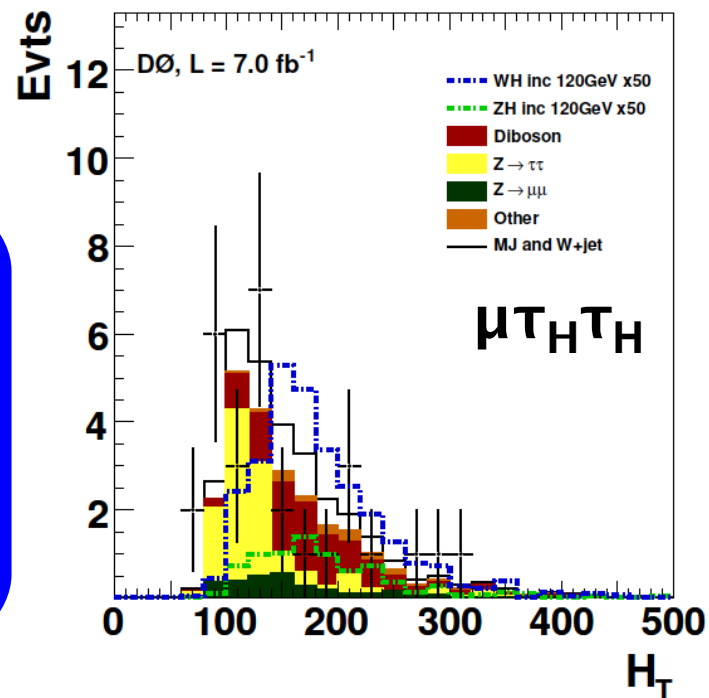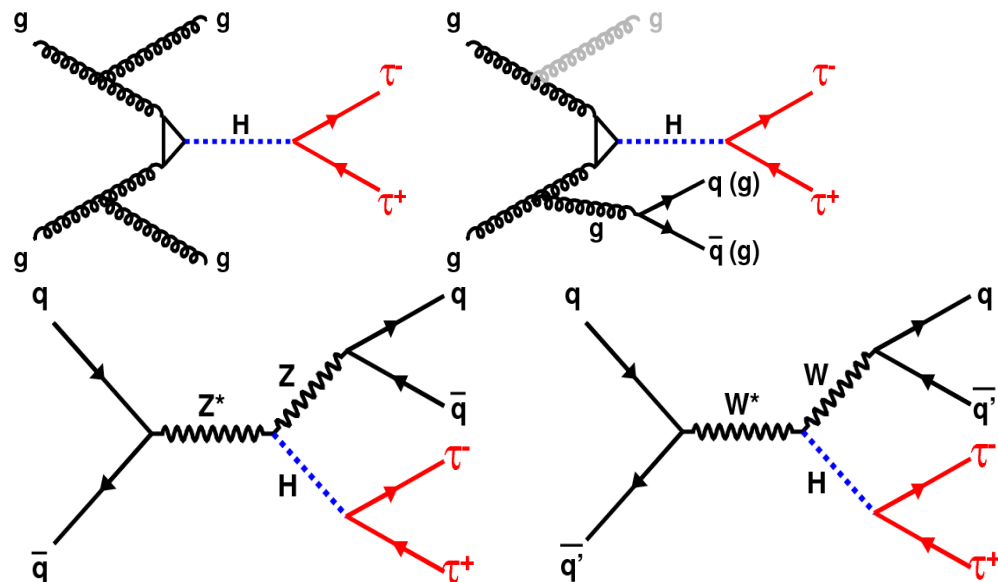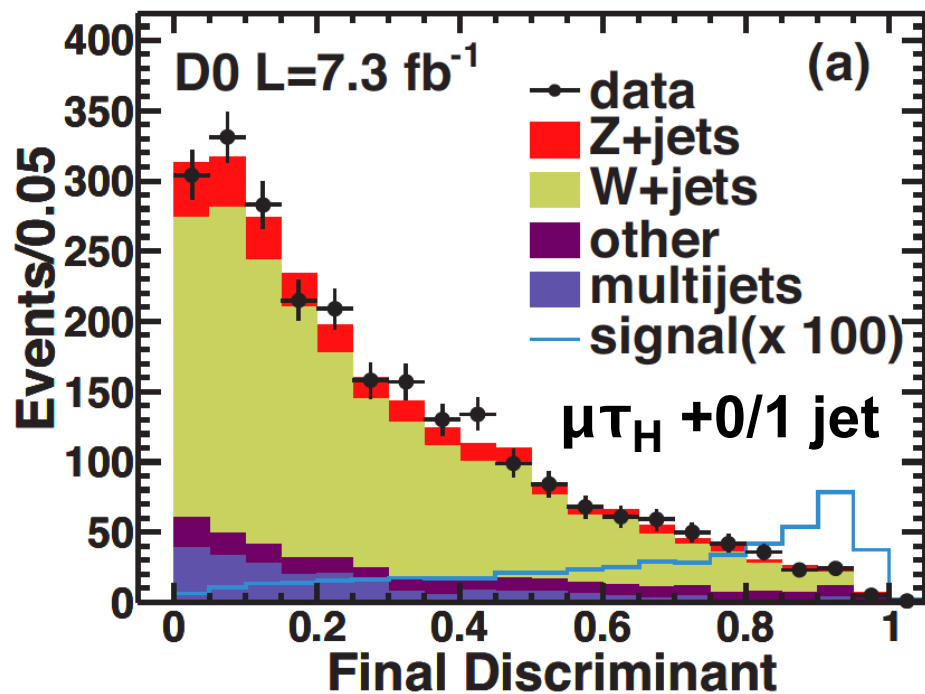
H → ττ decay rate: 5-10%

Also can get τ from W/Z decays

Many significant signal processes

DØ, L = 7.0 fb⁻¹
- WH inc 120GeV x50
- ZH inc 120GeV x50
- Diboson
- Z→ττ
- Z→μμ
- Other
- MJ and W+jet

$\mu\tau_H\tau_H$

Evts vs H_T

Diphotons

DØ preliminary, 9.7 fb⁻¹

Events per 5 GeV bin vs $M_{\gamma\gamma}$ (GeV)

Important channel at the LHC

Study at the Tevatron as well

Can be sensitive to new physics (fermiophobic Higgs)

DØ preliminary, 9.7 fb⁻¹

- Data
- $\gamma\gamma$
- γ+jet
- jet+jet
- $Z/\gamma^* \to ee$
- signalx100 (M_H=120 GeV)

Events per 0.08 bin vs BDT output
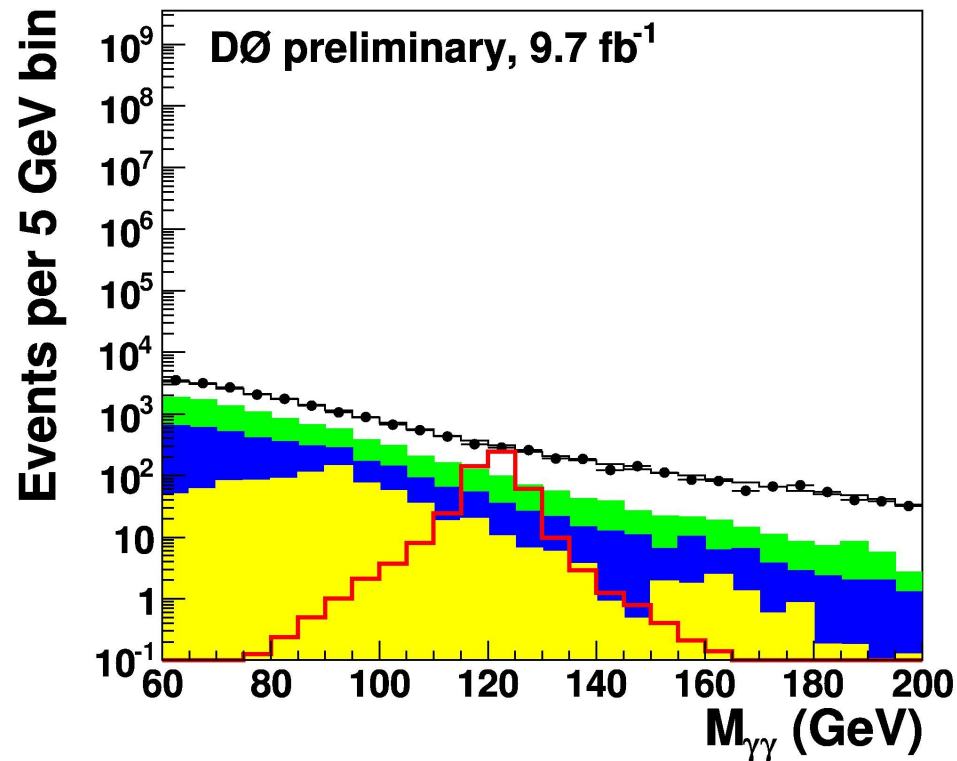
Backgrounds from control samples and Monte Carlo

Multivariate analysis to enhance sensitivity
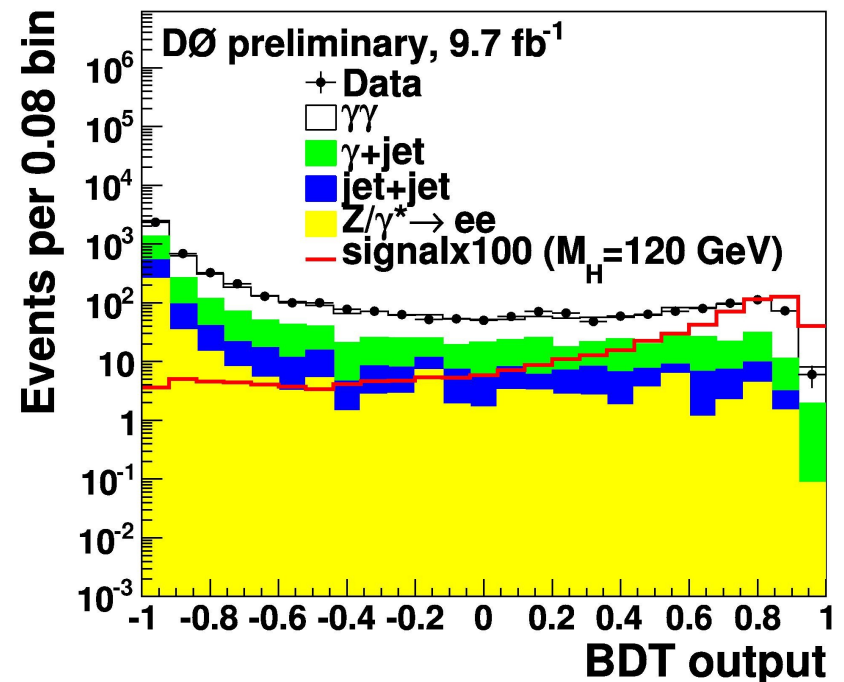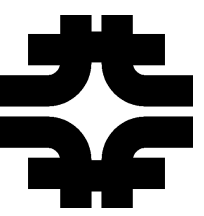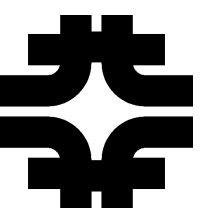
Results

The Log Likelihood Ratio

Test statistic used to extract results
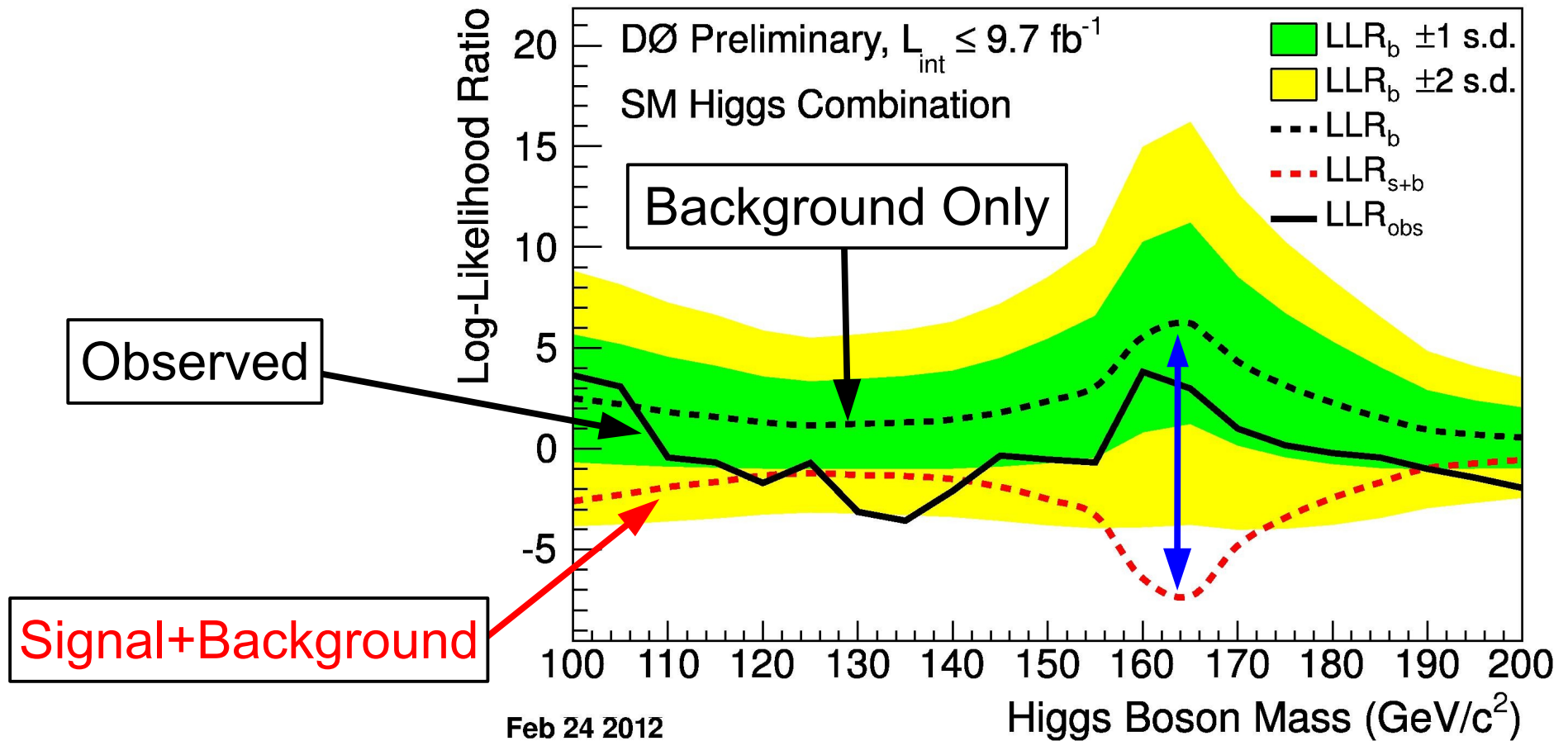
Based on Poisson likelihoods for two hypotheses:
signal+background
background only

Separation between points acts like $\Delta\chi^2$ of fits to models

Taking it to the Limit
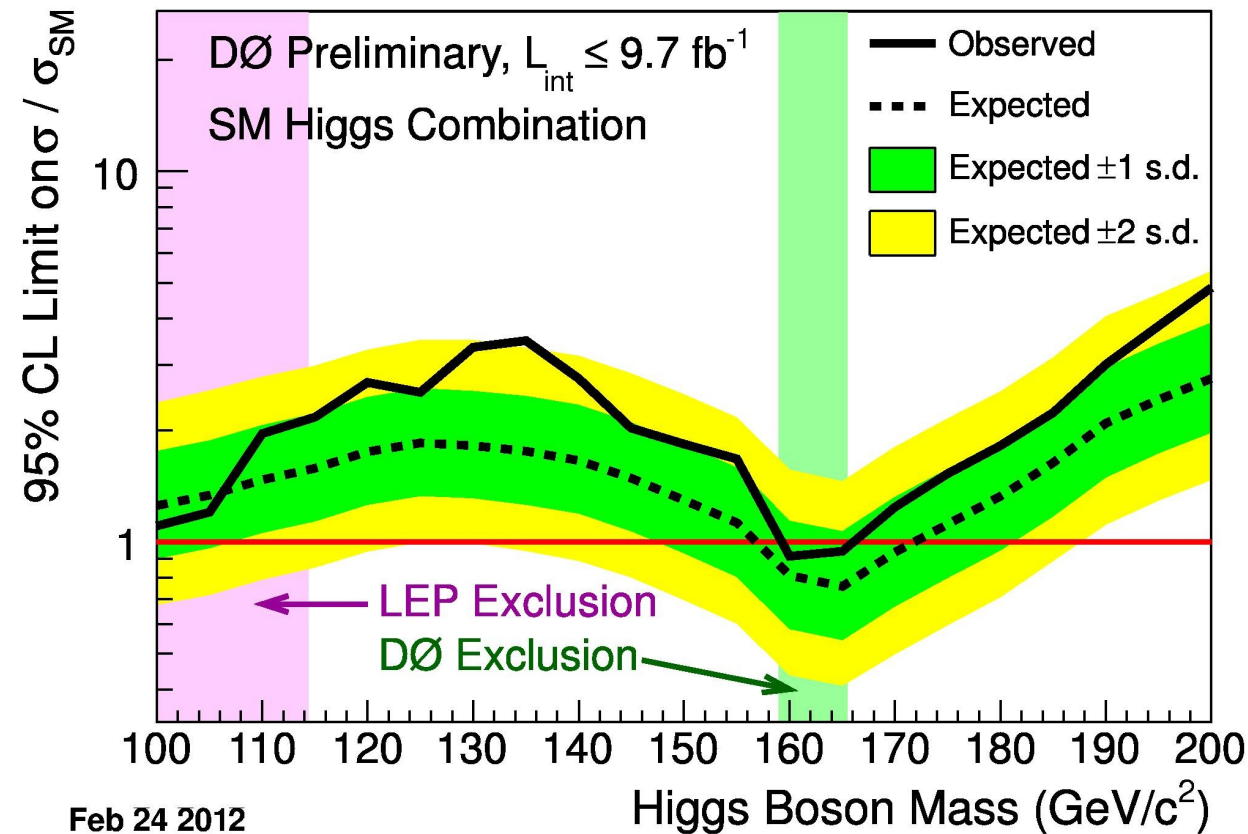
Exclusion at 95% CL:
159 < M_H < 166 GeV
Expected Exclusion:
157 < M_H < 172 GeV

Limits at M_H=115 GeV:
Exp: 1.58×σ_{SM}
Obs: 2.17×σ_{SM}

Limits at M_H=125 GeV:
Exp: 1.85×σ_{SM}
Obs: 2.53×σ_{SM}

Expected limits < 2×σ_{SM}
for all M_H<190 GeV

Comparison to Previous Results

Summer 2011
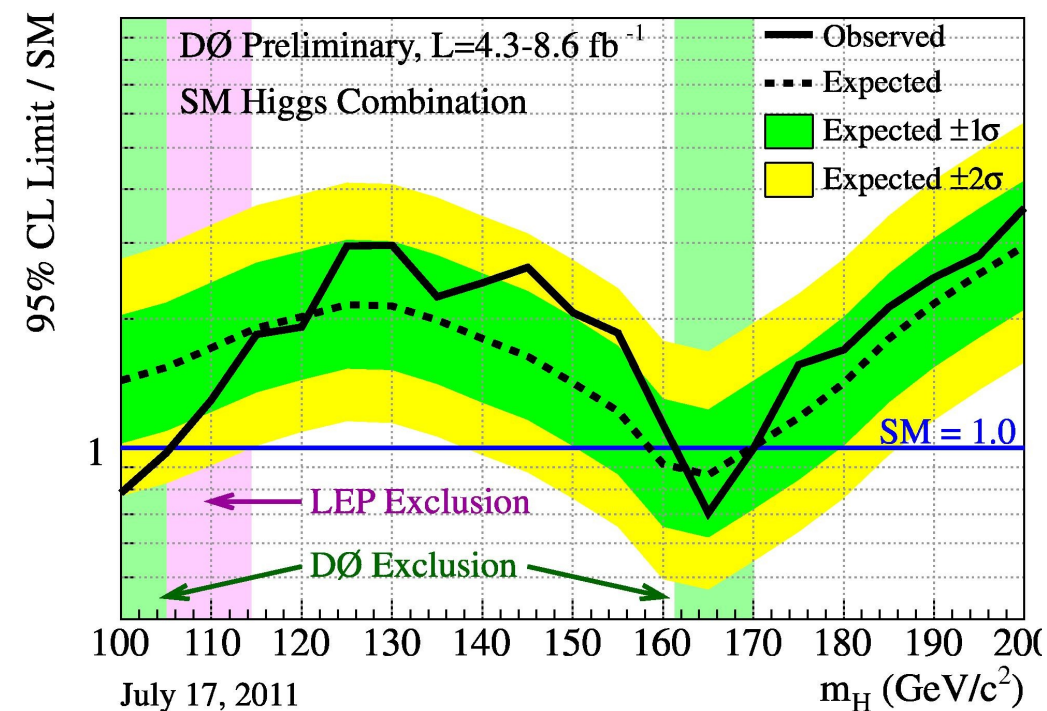
Today

Broadly consistent with results from last summer
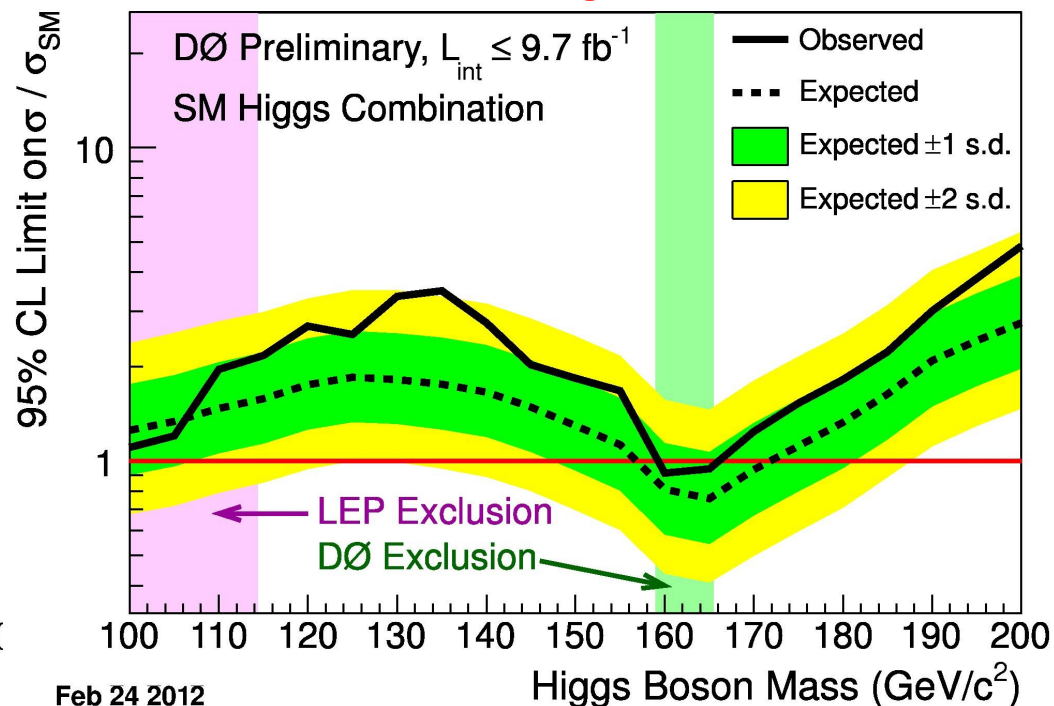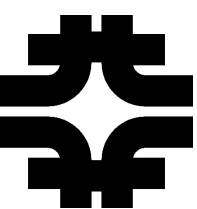
Expected Limits improved by ~10%

p-Values

Another way to visualize the results
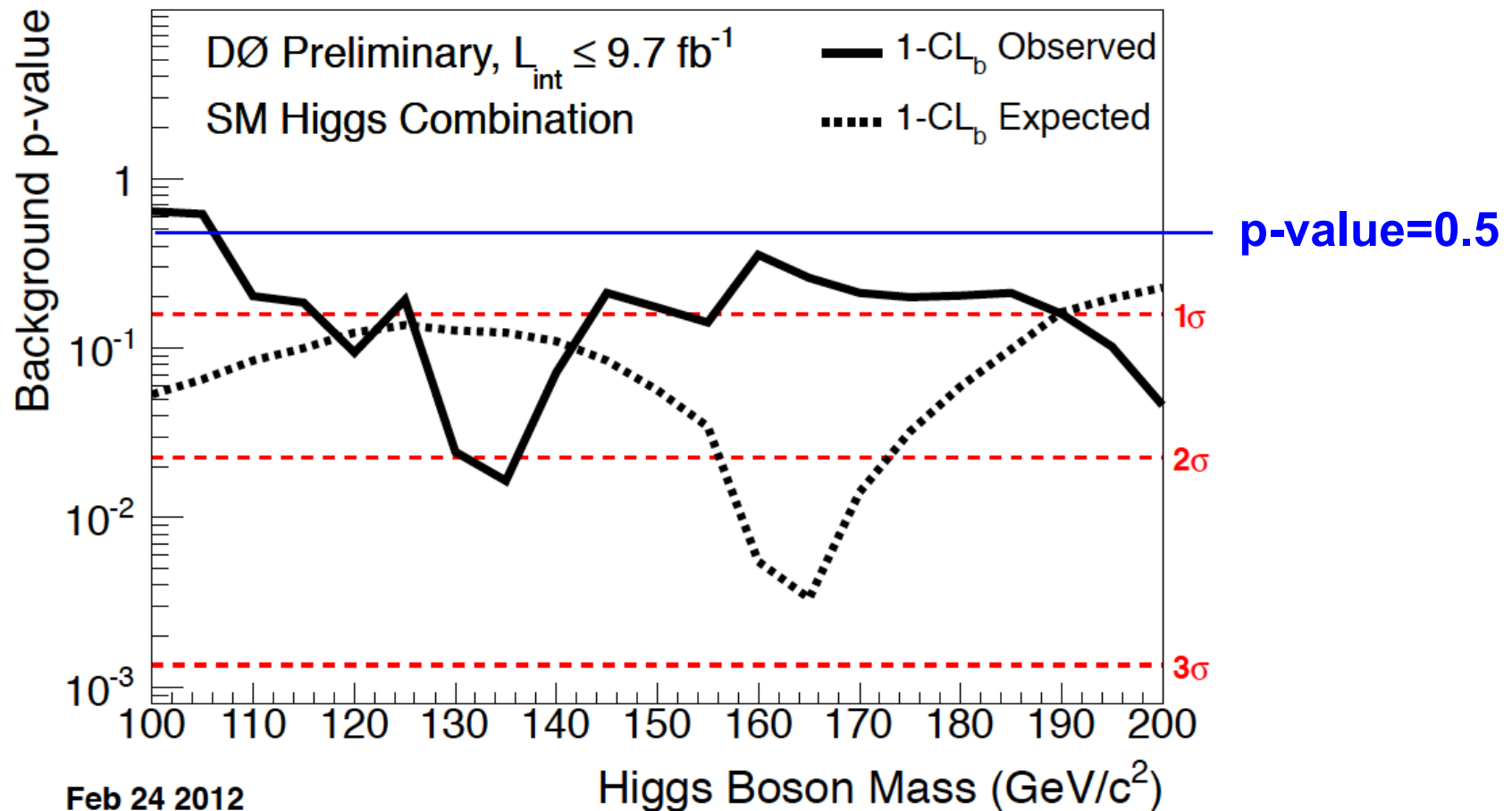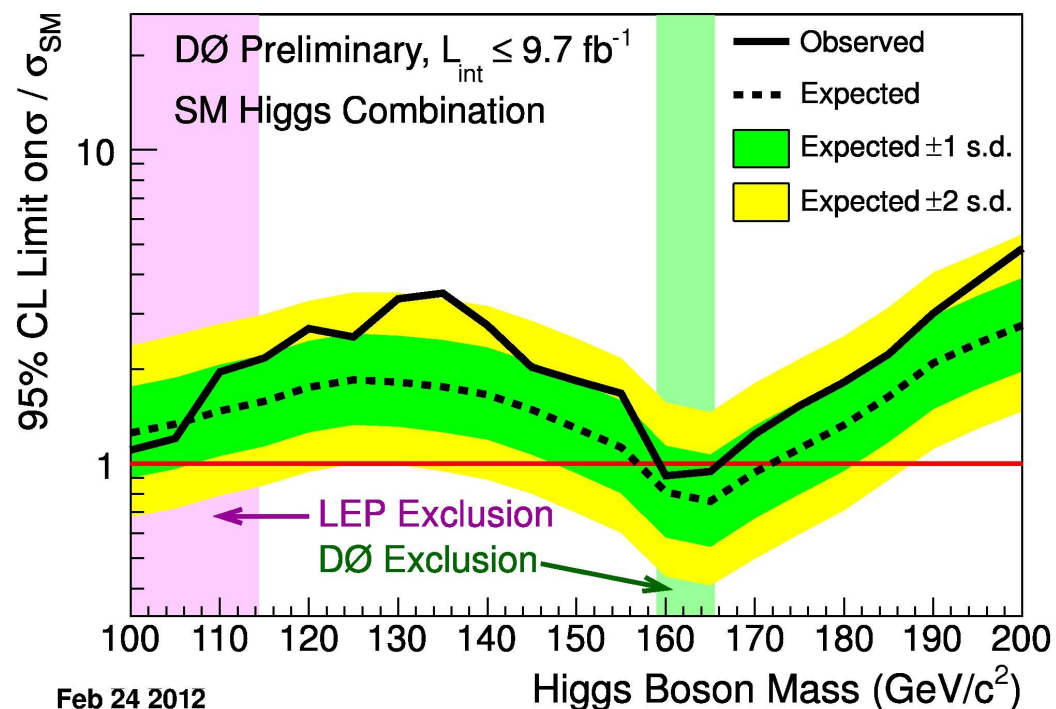

Not corrected for look-elsewhere effect

Summary

Both direct searches and indirect constraints are pinning down the Higgs

Evidence for VZ→X+b$\overline{\text{b}}$ used as a proving ground For the H→b$\overline{\text{b}}$ search

Excluding at 95% CL 159 < M$_H$ < 166 GeV

Excess around 115-140 GeV with local significance of roughly 1-2σ

DØ Preliminary, L$_{int}$ ≤ 9.7 fb^{-1}
SM Higgs Combination

— Observed
···· Expected
Expected ±1 s.d.
Expected ±2 s.d.

95% CL Limit on σ / σ$_{SM}$

LEP Exclusion
DØ Exclusion

Higgs Boson Mass (GeV/c^2)

Feb 24 2012

Promising improvements still to come:

Jet energy resolution b-tagging Multivariate techniques
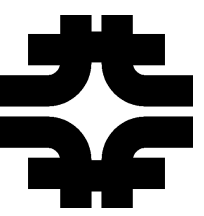
Backup Slides

The LLR: Then and Now
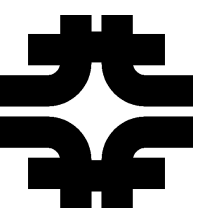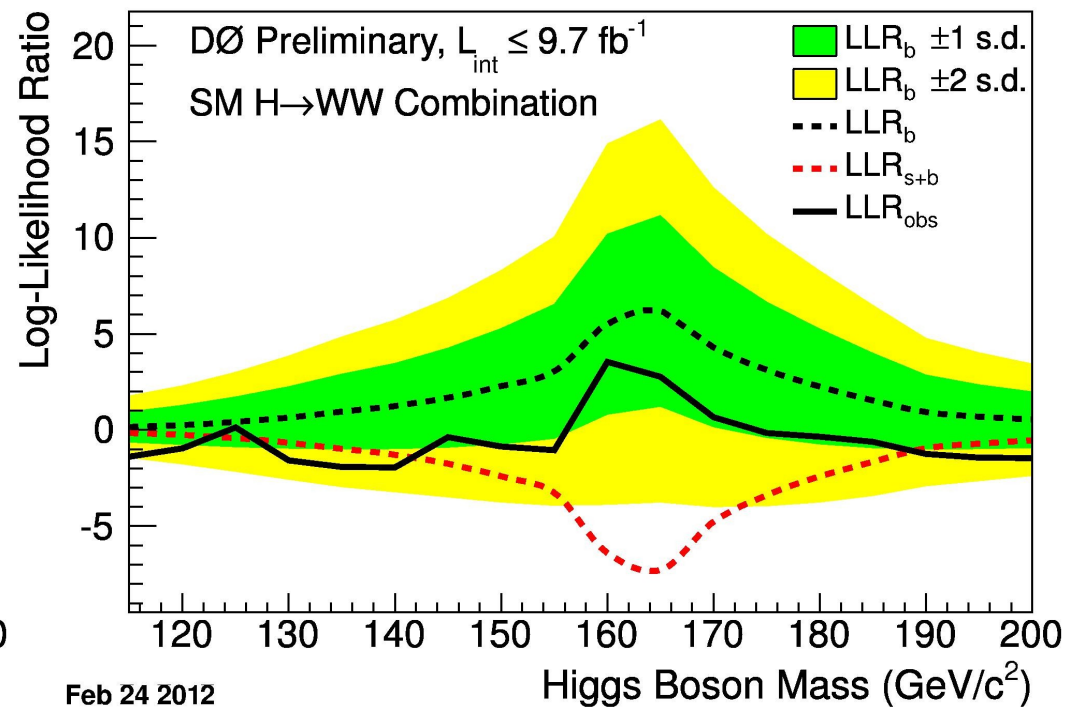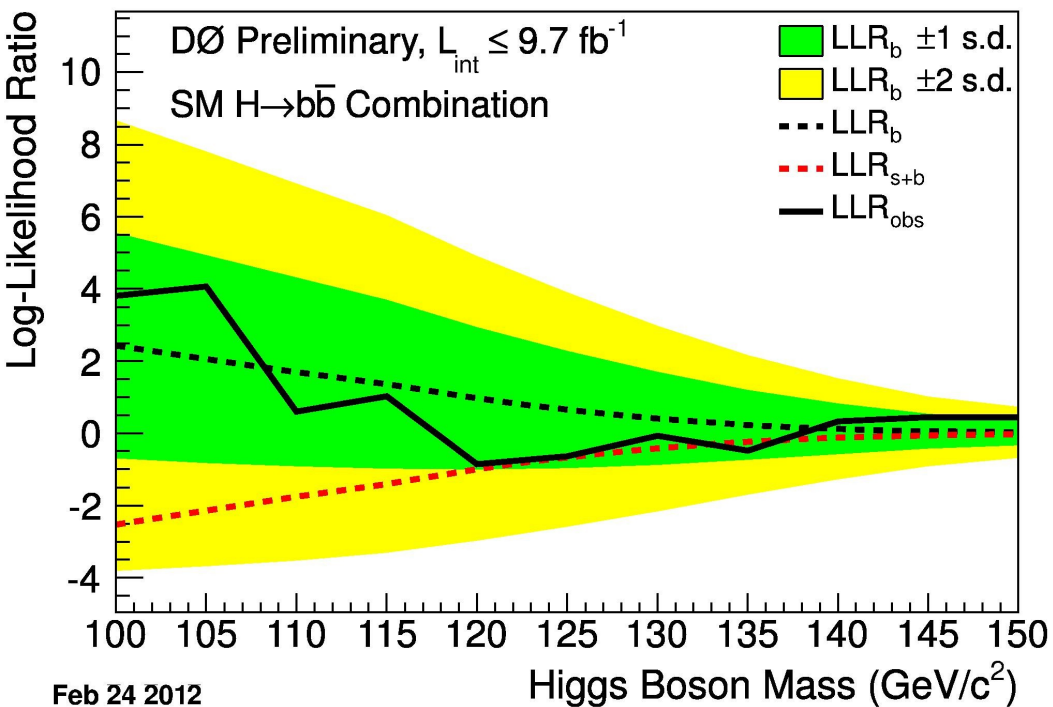
Summer 2011
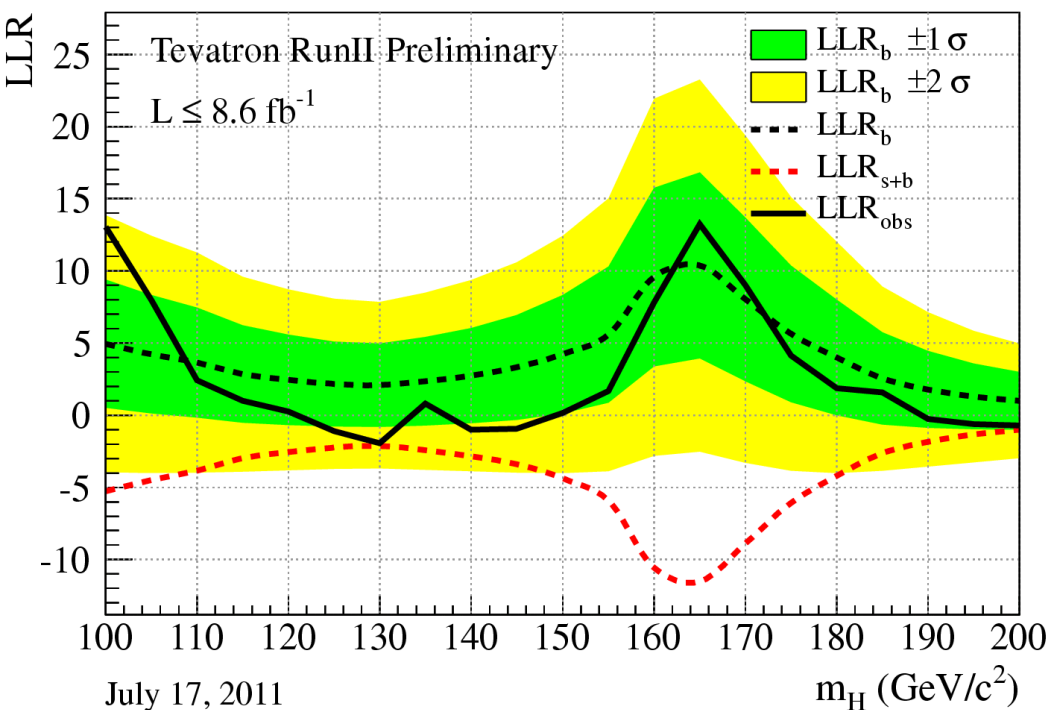
Today
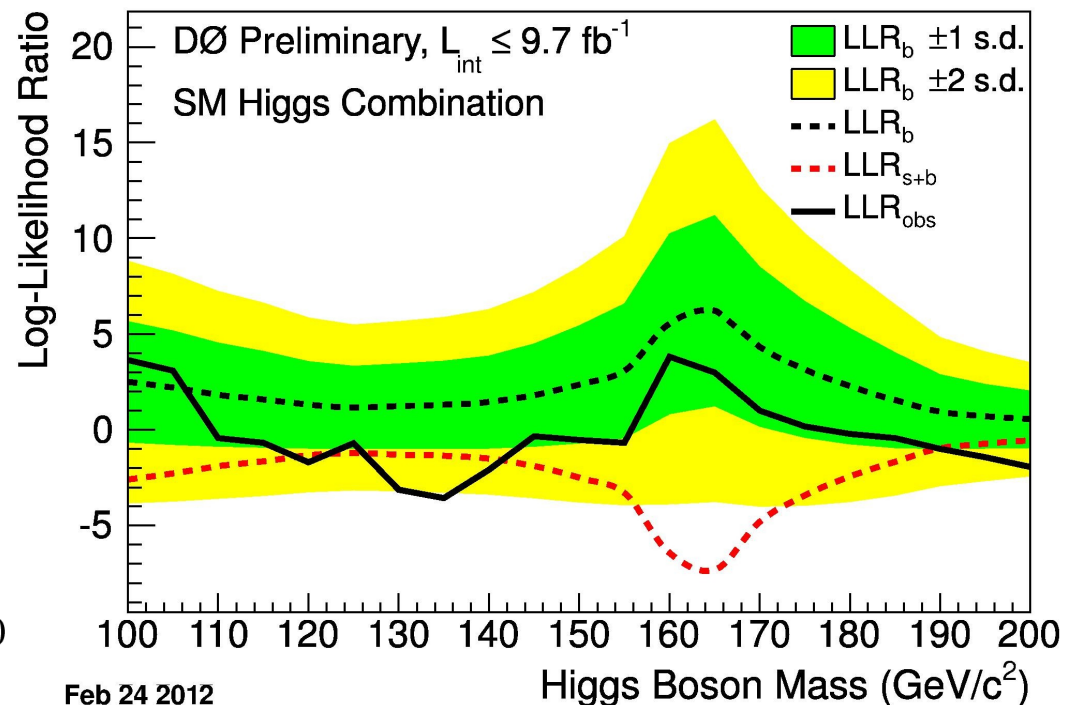
LLRs by Decay Mode

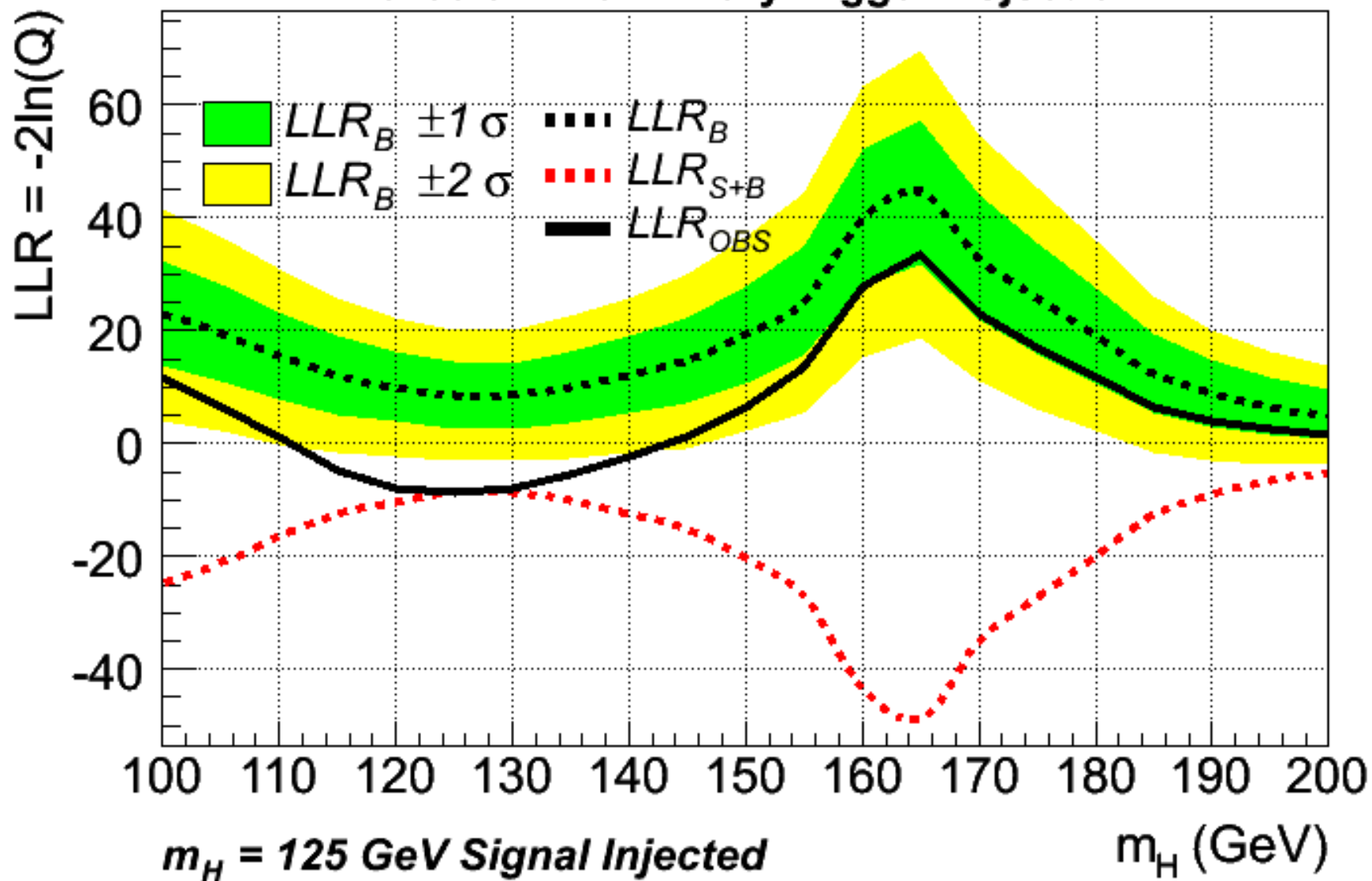# Signal Injection Tests

Tevatron Preliminary Higgs Projection
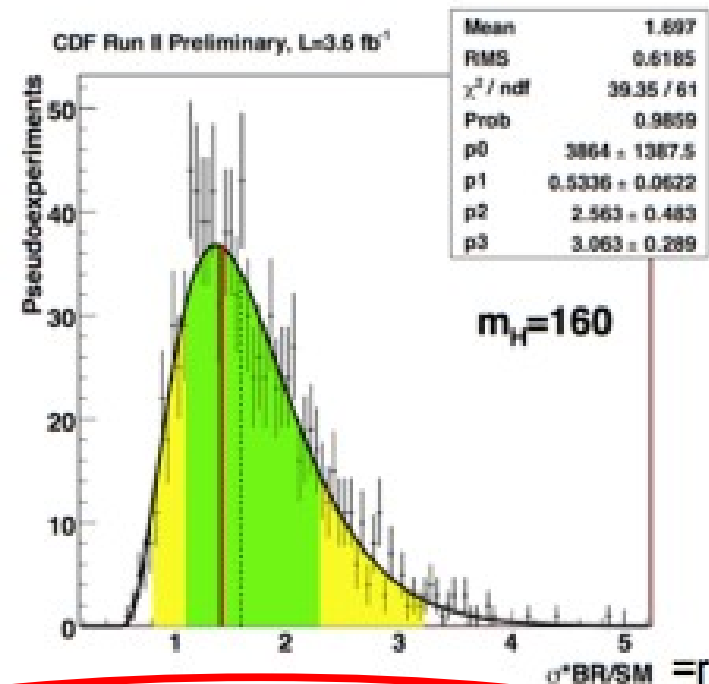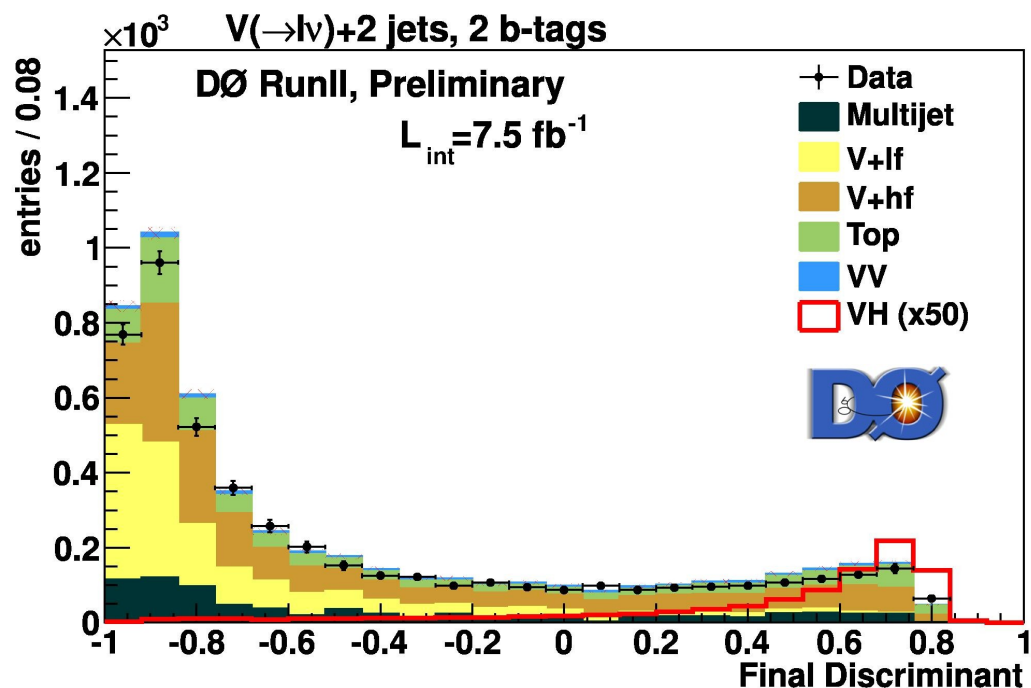
$m_H = 125$ GeV Signal Injected
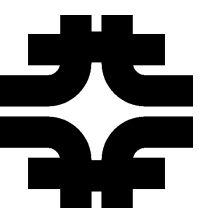
Higgs Cross Section Fit
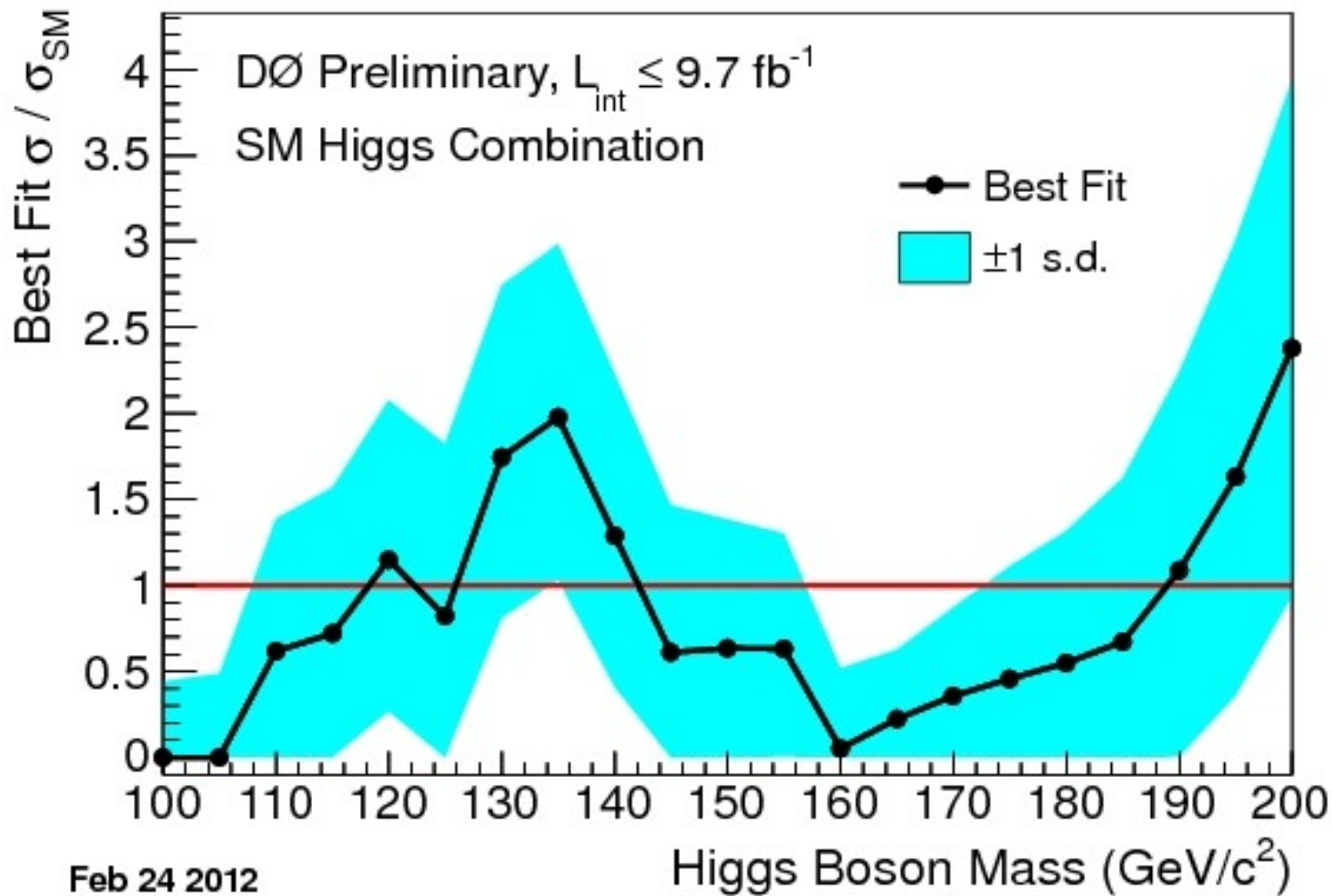
Bayesian Method

- Use Bayesian method

- Use CLs as cross check

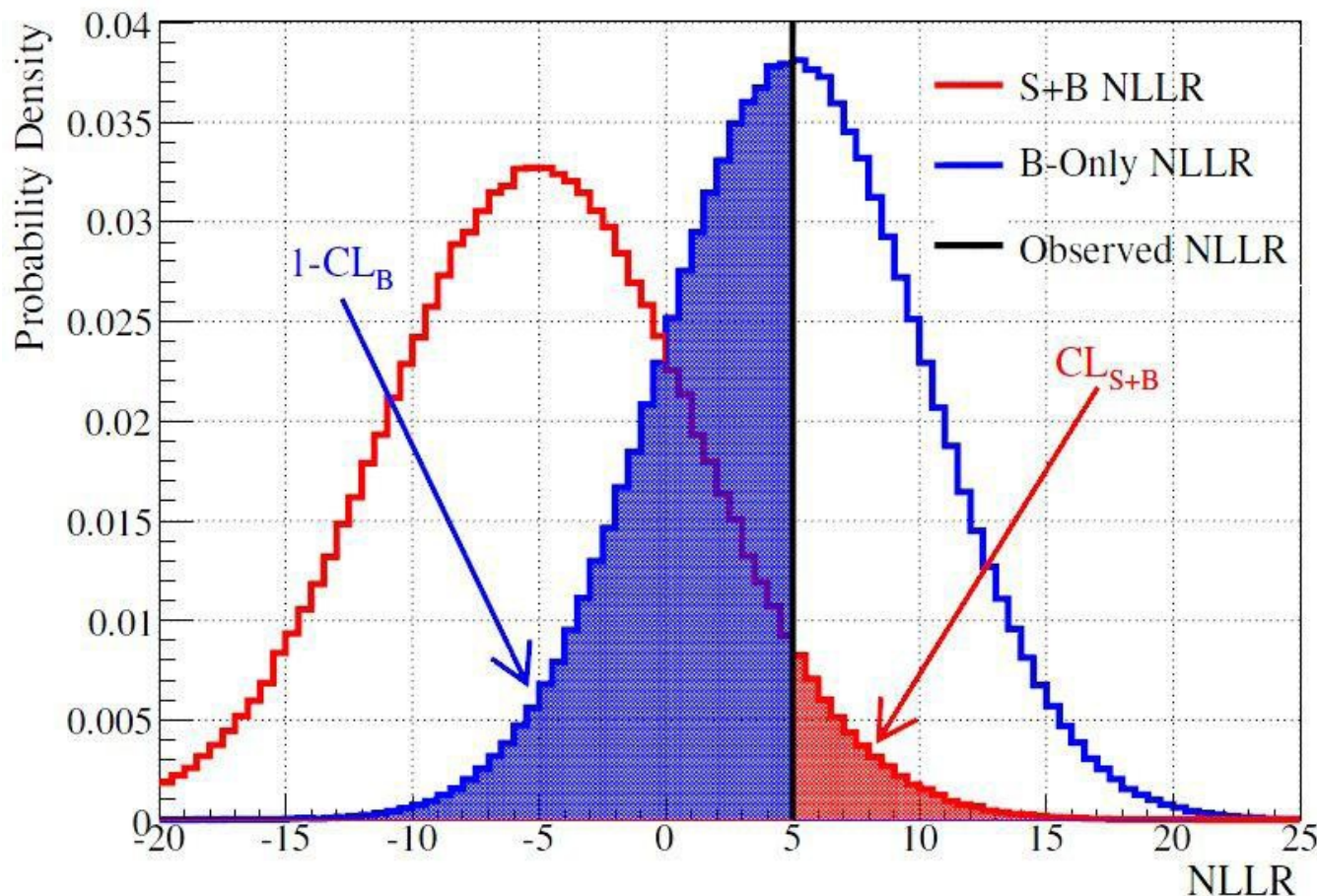- Agree within 2% on average (at worst 10% depending on M_H)

$$\prod_i^{bins} Poisson(x_i | B_i(\theta) + RS(\theta))$$

$$0.95 = \frac{\int_0^{limit} dR \int L(RS, B, x, \theta) d\theta}{\int_0^{\infty} dR \int L(RS, B, x, \theta) d\theta}$$

Adding Some Details

$$NLLR(x) = -2\ln\left(\frac{P(x|H_{S+B})}{P(x|H_B)}\right) \quad \prod_i^{\textbf{bins}} Poisson(x_i|B_i)$$

Integrate over systematics

$$CL_S = \frac{CL_{S+B}}{CL_B}$$

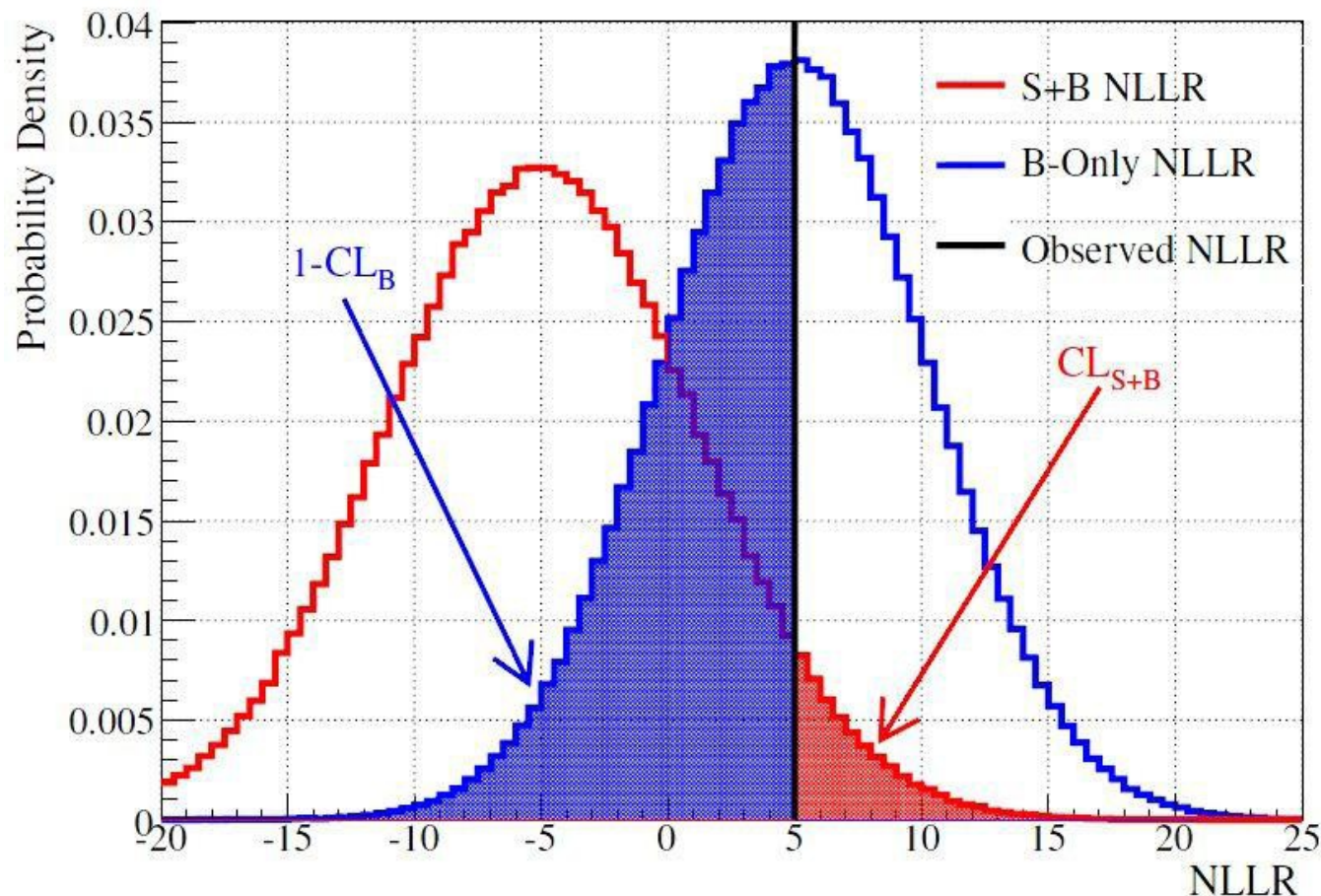Limit at $CL_S = 0.95$

- S+B NLLR
- B-Only NLLR
- Observed NLLR

$1-CL_B$

CL_{S+B}

Alternatively

$$NLLR(x) = -2\ln\left(\frac{P(x|H_{S+B}, \theta_{S+B})}{P(x|H_B, \theta_B)}\right)$$
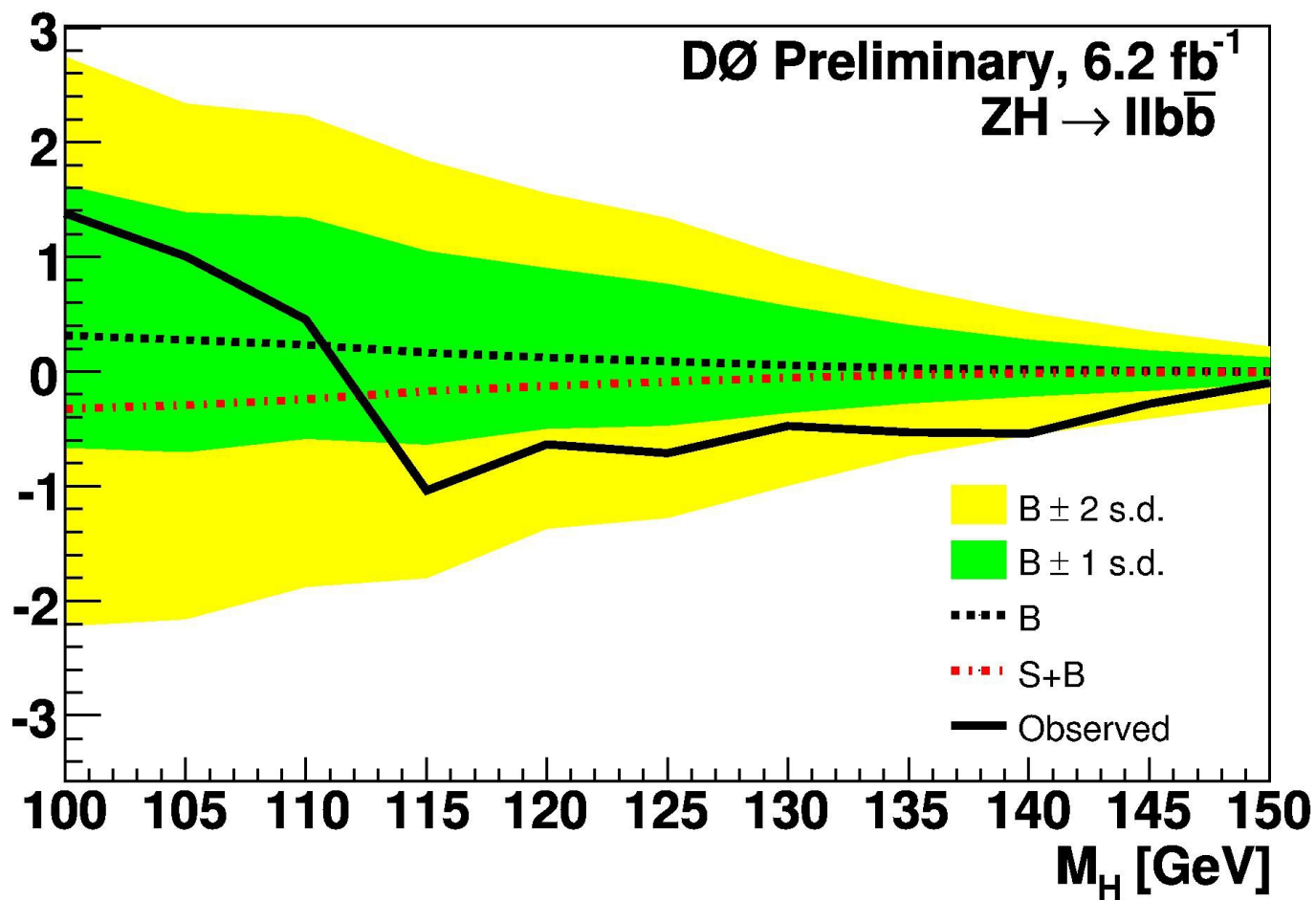
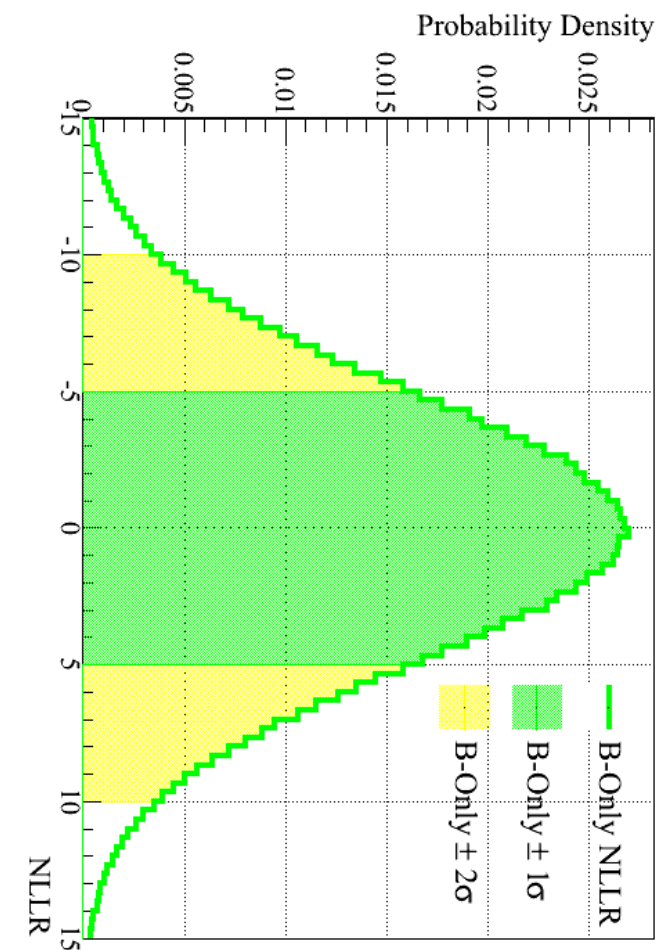θ_α – best fit of systematics to (pseudo-)data

$$CL_S = \frac{CL_{S+B}}{CL_B}$$

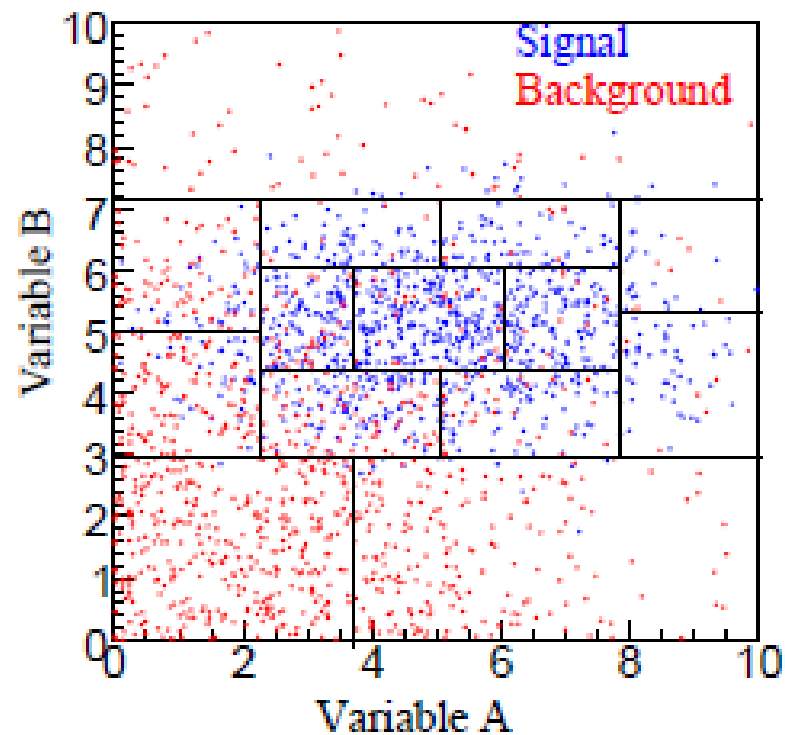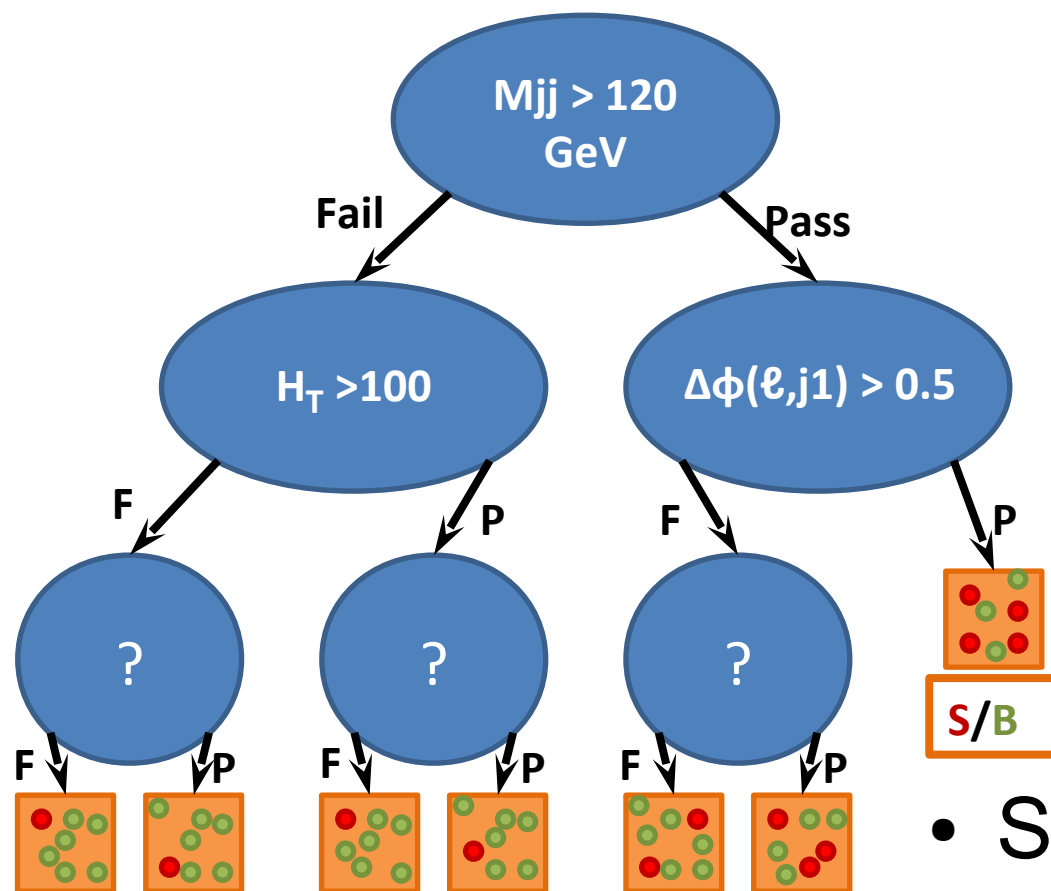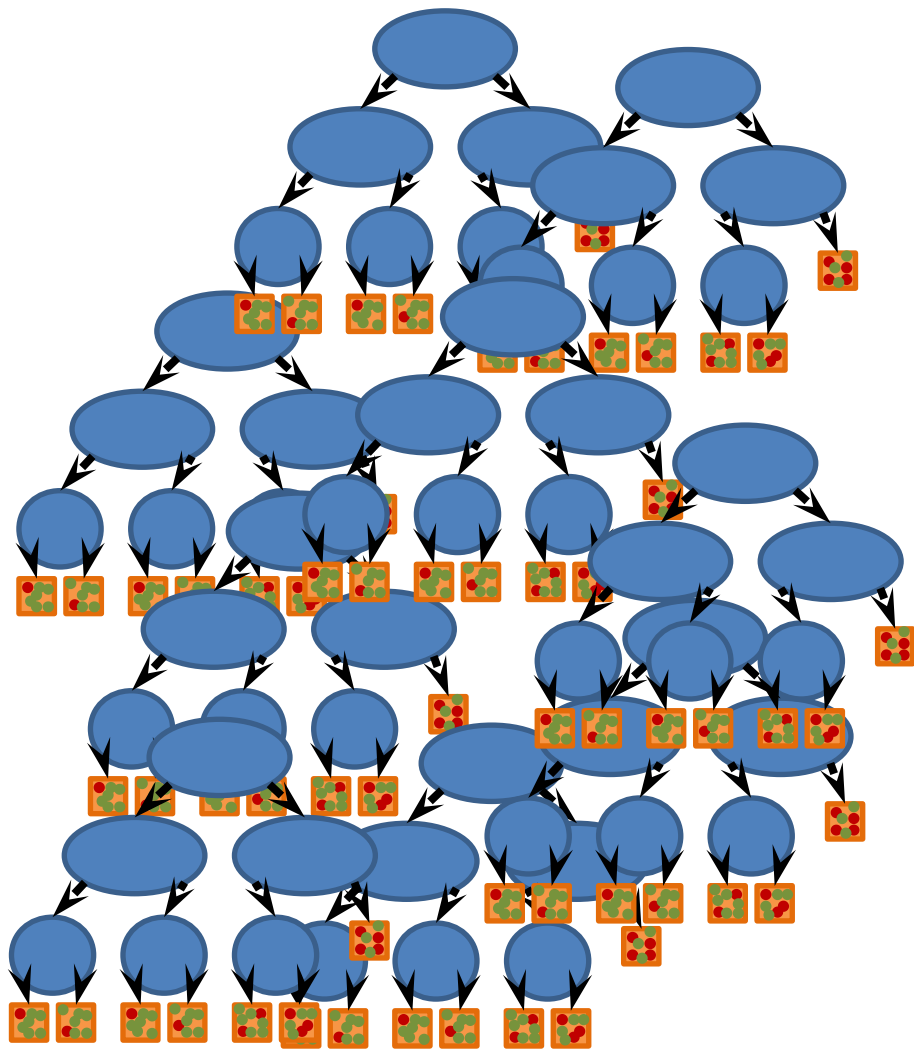Limit at $CL_S = 0.95$

As a Function of Mass

Decision Trees

- Slice up phase space with successive cuts
- Group together events with similar S/B

Random Forests

- Can do even better
- Train lots of decision trees
  - Each tree gets a random subset of events
  - At each node check a random subset of variables
  - Take the performance weighted average
- Need to take care...